THE
JOURNAL OF GEOLOGY

MAY–JUNE, 1909

UPPER CARBONIFEROUS

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VI

The Upper Carboniferous, rather in contrast with the Lower, was a period of emergence of shores and of shallowed waters, and it presents the variety that appertains to such conditions. In considering the stratigraphic relations of the Pennsylvanian and Permian one cannot fail to be struck by the local character of the phenomena, and the vast amount of detail, from which it is difficult to disengage facts of broader significance. One of the facts of larger moment is the general unconformity which occurs at the base of the Pennsylvanian rocks. The extent of the phenomenon may be gauged by this: that an unconformity probably occurs at this horizon all the way from Pennsylvania to the Mexican boundary, except possibly in the deeper troughs. The underlying strata range in age from pre-Cambrian to Upper Mississippian. This is evidently, therefore, an unconformity by overlap, but the overlap is sometimes not appreciable unless extensive areas be kept in view. Very rarely, I believe, is any angular unconformity to be observed, but there are basal conglomerates and in many places unmistakable evidence of erosion in the subjacent strata. Some of the most noteworthy instances of erosion are to be found in Missouri where shales of Pennsylvania age were deposited in sink holes and subterranean channels in the

[1] Read before Section E of the American Association for the Advancement of Science, at the Baltimore Meeting, December, 1908.

Lower Mississippian limestones. On the other hand, evidences of erosion are often wanting and sometimes any physical suggestion of an interruption in sedimentation. A striking instance of this sort occurs in southern Arizona. In the Bisbee area limestones of Pennsylvanian age rest upon limestones of Lower Mississippian age, the two series being extremely similar in physical characters, though carrying different faunas. The same condition probably exists in the Redwall limestone of the Grand Canyon region, whose lower part is of lower Mississippian age and whose upper has furnished, according to Meek, a long list of Pennsylvanian species. The presence of this unconformity is to be detected therefore not always by local evidences of erosion or changes in sedimentation, but sometimes only by paleontologic evidence in the abrupt and great change in the faunas and floras, and by stratigraphic evidence in the overlap, sometimes appreciable only by considering rather wide areas.

Inasmuch as we find this extensive area in which a hiatus exists at the base of the Pennsylvanian, and inasmuch as over part of the area unmistakable evidence of erosion is found, the inference is probably a safe one that everywhere within this region the hiatus is partially at least due to post-Mississippian erosion.

The presence of this erosion period implies the existence of a land surface over the eroded area, for the alternative hypothesis of submarine erosion may probably be disregarded.

The boundaries of the land cannot be exactly defined. On the east I would judge that it must have followed a presumably irregular line southwestward from northern Pennsylvania to southwestern Texas. At least, there is a well marked unconformity west of such a line, while in some sections east of it, sedimentation appears to have been continuous from the Mississippian into the Pennsylvanian. An estimate of where the boundary lay on the western side is conditioned somewhat by our correlations of the western Mississippian faunas with the eastern and with one another, especially as to areas over which the Upper Mississippian is wanting.

It is pretty well established by many observations that faunas with a Kaskaskian facies are not known west of the Mississippi Valley. There are, however, some faunas peculiar to the West which may be of Kaskaskian age. The best known and most notable of these

occurs in the Baird shale of California, and has not been found elsewhere on the continent. It is characterized among other things by the European *Productus giganteus*, and can be correlated more easily with the Mountain limestone of Europe than with our own Mississippian.

Although the *Productus giganteus* fauna strictly speaking is, so far as we know, restricted to California, there is another western fauna having a different facies which I am inclined to correlate with it. It comprises little besides corals, chiefly large Cyathophylloids. I have noted it in Utah, Montana, and Idaho. We have some reason to believe that it represents the Upper Mississippian to the East and the Baird fauna to the West. If this is so, the evidence upon which we chiefly relied for recognizing post-Mississippian erosion—the absence of the Upper Mississippian—is lacking over this area and the hypothetical land mass would appear to have extended westward on its northern margin no farther than western Montana and central Utah.

As to what were probably the northern and southern boundaries, evidence is wanting, Carboniferous strata being absent in Canada across its trend and absent or concealed by Cretaceous overlap in Mexico except just over the Texas border in the state of Chihuahua.

The unconformity of which I have just been speaking occurs at the base of the Upper Carboniferous. There is, however, a second important unconformity which occurs in the middle of the Upper Carboniferous and is less widespread as to the area in which it has been recognized. Like the other, it is marked rather by overlap than by discordance. The overlap is most conspicuous in western Texas and New Mexico, but equivalent strata, distinguished from the preceding ones by a distinct faunal change, and in some cases by basal conglomerates, probably extend into Arizona and Nevada, or even farther.

Lithologically the beds of the Upper Carboniferous and Permian present the greatest variety, and about the only truth of broad applicability has long been known. I mean that in eastern North America the sediments of the Upper Carboniferous are chiefly shales, sandstones and conglomerates with some thin limestones, while in the West the limestones have a much larger development, and

coals, which toward the East play so important a part, if not in thickness at least economically and significantly in the Carboniferous sediments, are there practically absent. From this it has been justly inferred that the character of the eastern Carboniferous indicates shore and estuarine conditions of deposition, while that of the western indicates marine conditions of deposition. There are, however, vast amounts of sandstone and shale in the Upper Carboniferous of the West.

It seems to be true that the greatest deposits of limestone in this series are found rather to the Southwest than to the West and the most notable thicknesses of sandstone and conglomerate rather to the Northeast than to the East.

There is one other phenomenon of more than local interest which should not be omitted in a commentary on the lithologic features of the Upper Carboniferous. I refer to the red beds of the West and Southwest. The age, the stratigraphic relations, the sources, and the cause of the peculiar coloration of this great series of sandstones and conglomerates form a problem of no mean difficulty and importance. Although it is difficult to trace these beds stratigraphically, and though fossils are rarely found in them, we know now that sediments of this character were formed rather early in the Pennsylvania and successive manifestations recurred at various periods on into the post-Cretaceous. That there were continuous red beds conditions during all this period seems out of the question, and also that red beds conditions repeatedly recurred. Some of the occurrences can probably be best explained as a reworking of older materials under conditions unlike those which determined their original character.

In considering the faunas of the later Paleozoic—those of the Pennsylvanian and Permian—several facts of a general nature can be stated. The Upper Carboniferous faunas of western North America have a facies markedly different from those of the eastern part and are closely comparable to the corresponding faunas of Asia and eastern Europe. A second fact of general import seems to be that, quite in contrast to the unstable physical conditions in which they lived, these eastern faunas, which range, let us say, westward to the Rocky Mountains, are remarkably uniform both in their geographic distribution and in their range. I would be far from saying that the

Upper Carboniferous faunas of the continental basin do not show differentiation during this long interval, for the Pottsville group has a distinct fauna and appreciable changes occur in the later Pennsylvanian. But the changes are by no means so marked as one would be led to expect from the thickness of the strata involved, the extent of the territory they cover, and the varying conditions of the time and the place. The truth of this statement will be appreciated upon a consideration of the Mississippian series of the Upper Mississippi Valley and the subdivisions which have been established in it.

When we speak of the variety of conditions under which the sediments in question were laid down, and remember that they include the great coal deposits of this era, we are led to inquire whether the faunas are marine or fresh water, or perhaps both, with the important difference in facies which such difference in habitat would doubtless entail. Fresh-water faunas, or at least fresh-water genera and species, have been recognized elsewhere in the Carboniferous, notably in the Coal Measures of England and the Permian of Russia. In North America, although we have a facies which appears to be non-marine, there are no Carboniferous faunas which in my belief can be called fresh water. The facies in question recurs frequently, particularly in the Appalachian region, and manifests little change in its general aspect, although appearing at widely different horizons in the Pennsylvanian. It is very restricted in variety though often abounding in individuals. A mollusk probably identifiable as *Naiadites elongatus* Dawson is a characteristic feature. Ostracods are also abundant, and the large bivalve Crustaceans, *Estheria* and *Leaia*, sometimes occur. *Spirorbis* is another type frequently met with, while fish scales, fragments of *Limuloid* Crustaceans, and wings of insects are rare. Usually this peculiar assemblage of forms is associated with abundant coal plants.

The genus *Naiadites* was described by Dawson from the Nova Scotia Coal Measures, in which it occurs with a fauna similar to that sketched above. Dawson regarded the sediments and faunas as representing fresh-water conditions, and considered *Naiadites* to be related to the Naiads of our fresh-water lakes and rivers.

The fresh-water mollusks of the English Carboniferous were included by Dr. Wheelton Hind under the three genera, *Anthracoptera*,

Anthracomya, and *Anthrocosia* in a valuable monograph published a few years ago. Later, after studying specimens of *Naiadites* from Nova Scotia, he reached the conclusion that *Anthracoptera* and *Naiadites* were the same genus.

Thus far the balance of evidence and opinion seems to be in favor of the fresh-water habitat of the fauna. On the other hand, externally and internally, *Naiadites* is extremely like the marine genus *Myalina*, and Dr. Hind has referred many of our marine *Myalinas* to *Naiadites*. In fact, he has even placed the names of some of our American *Myalinas* which always occur associated with marine faunas in the synonymy of English species of *Naiadites* which are supposed to be strictly fresh water. Furthermore, the fauna under consideration is in some instances associated with specimens of *Lingula* and *Aviculipecten*. The living *Lingulas* sometimes inhabit brackish waters near the mouths of rivers, but never the fresh waters of lakes and streams, while the living *Pectinoids* are strictly marine. The fossil Pectinoids in question are small and depauperate examples and belong to a rather peculiar group, that of *Aviculipecten whitei*.

This assemblage can hardly be explained as due to the accidental commingling of types having different habitats. If it consisted of fresh-water animals washed out to sea we would expect to find the fresh-water types few and the marine ones numerous, varied, and characteristic. Such is not, however, the case. One would not a priori much expect to find marine animals washed into a fresh-water fauna, and in such an event we would probably look for an entire marine fauna, or, at least, granting that only a few specimens were washed in, that some such invaders would be of the usual marine types. Instead, the alien forms are always limited to one or two peculiar varieties. That abundant and differentiated marine life was always at hand waiting for an opportunity to migrate wherever the conditions became possible seems to be evidenced by the occurrence now and again of marine faunas in close association with beds of coal. On the whole, it seems most reasonable to regard this fauna as a natural assemblage of species selected and modified by a habitat, if not in strictly marine, at least not in strictly fresh waters.

There is another reputed occurrence of fresh-water forms in the Carboniferous, reported by Mr. Walcott from the Eureka district, of

Nevada. I have examined the fossils in question only casually, and it has been many years since I have seen them at all, but I doubt whether in this instance, any more than the other, the evidence warrants saying more than that they are possibly non-marine.

The Upper Carboniferous faunas of the West appear to be better differentiated than those east of the Rocky Mountains. At least three well-marked facies can be recognized. The oldest of these is found in the limestones whose occurrence has already been mentioned, resting directly upon Lower Mississippian limestones of similar character in Arizona and probably in Utah. This fauna is succeeded by one which is best considered from its development in the Transpecos region of Texas, because it is there more highly developed, more favorably studied, and more determinable in its stratigraphic relations with higher beds. It occurs in the Hueco formation which is 5,000 feet thick, and is practically calcareous throughout. As has already been noted, the Hueco formation by overlap rests upon the pre-Carboniferous in this region. The Mississippian faunas, together with the earlier Pennsylvanian ones, appear to be absent. The Hueconian fauna is widely distributed over the West, ranging indeed into Alaska, while it is even recognizable in Asia and eastern Europe. Most of the occurrences of Carboniferous in the West can be referred to this series, although some or them present more or less distinctive facies. The more important of the facies provisionally referred to the Hueconian are these: that of the Aubrey group of Arizona, rather widely distributed; that of the phosphate beds of the Preuss formation, local in Utah, Idaho, and Wyoming; the *Spirijerina pulchra* fauna with a considerable distribution in Idaho, Wyoming, Utah, and Arizona; the fauna of the McCloud limestone of California probably extending into Nevada; and that of the Nosoni formation of California (in part the "McCloud shale"), apparently recognizable to the eastward and to the North and West, even into Alaska.

In the Transpecos the beds of the Hueco formation are succeeded by those of the Guadalupe Mountains. The contact between the Hueco formation and the Guadalupian series is obscured by faulting and by desert deposits, but it is assumed that the interval between the highest known beds of the one and lowest known beds of the other is not a long one and that no unconformity exists between them. The

Guadalupian includes two formations, the Delaware Mountain formation and the Capitan limestone. The Delaware Mountain formation consists of sandstones and limestones, largely arenaceous to the North and largely calcareous to the South. The Capitan consists of whitish limestones and dolomites. Thus constituted the Guadalupian series is about 4,000 feet thick. The faunas of the two divisions of the Guadalupian are closely related to one another. They are very rich and varied, having already furnished over 325 species. The Guadalupian fauna is peculiar. But few of its species are common to the other American faunas and some of its genera, such as *Richthofenia*, *Leptodus*, *Geyerella* and *Aulosteges*, have not been noted elsewhere in the western hemisphere. Even the more common genera are in many cases represented by uncommon types. As an instance may be mentioned the genus *Composita* (*Seminula*), which, by the way, seems to be rather characteristic of our American faunas where it is ever present and ever abundant. In the Guadalupian this genus develops a bi-lobed species with a sinus on the dorsal as well as on the ventral valve and a deeply emarginated anterior border.

It is possible that the Guadalupian fauna may have an equivalent in California in the Robinson formation, in which I have noted a species of *Leptodus*, and a suggestion is contained in some forms from Nevada, but aside from this the Guadalupian facies is known only in a limited area in New Mexico and Texas.

It remains to speak of still another western fauna having a pronounced facies, a wide distribution, and a range through a considerable thickness of rocks. I mean the fauna of the so-called Permo-Carboniferous of the Wasatch Mountains, and the Permian of Mr. Walcott's Grand Canyon section. This fauna, which ranges also into Wyoming and Idaho, comprises little else than pelecypods, of which *Myalina* and *Aviculipecten* are the most common types, the Pectinoids being especially abundant and varied. It may tentatively be correlated with the Guadalupian (Delaware Mountain division), athough it presents but little resemblance to the Guadalupian fauna as at present known. At least, it appears to occupy a corresponding position in the section, resting upon strata which in the light of our present knowledge are correlated with the Hueco formation.

These western faunas are more easily correlated with those of

Europe, especially Russia, than with those much nearer geographically, in eastern North America. Indeed, the correspondence of our western faunas with those of Russia is truly remarkable. The Russian series consists, in ascending order, of the Mountain limestone, or *Productus giganteus* zone; the Moscovian, or "Lower Carboniferous;" the Gschelian or "Upper Carboniferous;" the Artinskian or "Permo-Carboniferous" and the Permian. One school of Russian geologists includes the Artinskian or Permo-Carboniferous beds in the Permian, and some Americans have followed them, but this seems to be of doubtful propriety. Murchison, DeVerneuil, and Keyserling mistook the Artinsk sandstone for the Millstone grit and distinctly excluded it from the Permian. If the faunal relations demand this extension of the term Permian to the Artinsk it would be justifiable, but such is not the case. At least, this appears to be the judgment of Tschernyschew, the chief of the Russian Survey, and other distinguished paleontologists at all events. In this recital the term Permian is used in exclusion of the Artinsk beds.

The *Productus giganteus* zone seems to be represented on this continent by the Baird shale of California whose fauna likewise contains *P. giganteus*.

The Moscovian, which has a facies very like our common Pennsylvanian faunas, may be compared with the earliest Pennsylvanian of Arizona and Utah, the term "Lower Carboniferous," as used by the Russians, having no relation to our own Lower Carboniferous or Mississippian. The Gschelian is clearly related to our Hueco formation, but with this zone the closeness of the analogy ceases. One is tempted to place in alignment the Artinsk and Permian which succeed the Gschelian in the Russian section, with the Delaware Mountain formation and Capitan limestone which succeed the Hueco formation in the American section, but such a correlation is neither sharply contradicted nor substantially supported by the faunal evidence. In fact, as exhibited in the literature, the faunas of the Artinsk and Permian are much less varied and individualized than those of the Guadalupian. The following suggestions are made with the diffidence of second-hand and imperfect knowledge, but it would appear that after the Gschelian stage there was in the Russian area a gradual progression from marine to at least near-shore conditions. This

seems to be indicated by the great reduction in the marine facies, especially in the brachiopod representation, so that in the Permian there remains scarcely a tithe of the greatly diversified brachiopod fauna of the Gschelian, and by the introduction of fresh-water types of which not less than 200 species have been recognized. Apparently the typical Permian deposits of Russia represent local and not normally marine conditions of deposition.

I am tentatively assuming, on the grounds noted above, that the Guadalupian is equivalent to the Permian or to the Permian and Artinskian, the one representing a normal marine and the other an abnormal facies. It may prove, however, that all or part of the Guadalupian is younger than the Permian. A recent monograph by Tschernyschew gives a complete account of the brachiopods of the Gschelian, but the other types remain undescribed or else the descriptions are badly scattered. The literature on the Artinskian and Permian is also somewhat scattered, but one receives the impression that the brachiopods of the latter do not present many positive differences from those of the Gschelian though much less varied, and reduced to a few types of long range and wide distribution. Whether the same is true of the rest of the fauna it is difficult to say, although it seems rather doubtful. In view of the striking difference between the faunas of the Guadalupian and the Hueco formation, in which the brachiopods are most in point, of a lack of a corresponding difference between the Gschelian and Permian, of the marked resemblance of the brachiopods of the Hueco and Gschelian, and of the lack of agreement between the Permian and Guadalupian, there is a possibility, if not a certain probability, that the Artinsk and Permian may be correlated with the Hueco formation.

Having compared the western faunas with those of Russia, let us consider what their relations may be with those of eastern North America.

We find in such a comparison really fewer resemblances than with the faunas of Russia. Of the three or four western faunas which I have noted, by far the greatest resemblance is to be found in the oldest of all; perhaps because it is least varied and most generalized. The Hueconian presents much more numerous and extensive differences and the Guadalupian the strongest of all. In fact, of the 325 species recognized in the latter scarcely a single variety can be definitely

identified in the eastern faunas. The species are in most cases not only not the same but they are not even similar. It seems possible to me that the Hueconian fauna may be equivalent, in spite of its differences, to the faunas of the East, but hardly that of the Guadalupian. This opinion is based upon the striking differences existing between the Guadalupian and any eastern fauna, upon the much closer resemblance of the eastern faunas with the Hueconian fauna, and upon the important differences between the latter and the Guadalupian. However, as so little is known of the character and potency of the environmental conditions under which these faunas existed, there is a possibility which I do not wish to deny that the relations noted may have to be ascribed to the environment element, rather than to the time element.

Provisionally I am regarding the Guadalupian as younger than any known faunas of the eastern region, thus interpreting the faunal differences of the Hueconian when compared with the Pennsylvanian and Permian of the East, as due to environment rather than to time. There is some evidence, however, that the Hueco formation should be considered younger than the so-called Permian of the Kansas section instead of equivalent to it. Mr. Beede has recently described several occurrences of a fauna which I should perhaps have mentioned as representing one of the interesting and important differentiations found among the faunas of the Upper Carboniferous of the East. They were obtained from the red beds of Oklahoma and the horizon is known to be considerably above the highest occurrences of invertebrate fossils in Kansas. This fauna appears to me to present more important differences from the Kansas Permian than exist between the latter and the underlying beds referred to the Pennsylvanian. Accordingly, if any of the faunas of the eastern section are to be classed as Permian it would appear to me more appropriate that the dividing line should pass above rather than below the Kansas Permian. When compared with the western faunas, that described by Mr. Beede is far from being identical either with the Guadalupian or with any facies of the Hueconian, but of the two its affinities appear to be decidedly with the latter. If this evidence is to be relied on, even Mr. Beede's fauna is older than the Guadalupian and if the latter is equivalent to the Permian, older than the Permian.

Another fact which might be brought forward to support the contention that even the Hueconian is younger than the Kansas Permian is the important unconformity which preceded Hueco sedimentation and was accompanied by a corresponding change in the subsequent fauna. According to this interpretation, the oldest of the western faunas, which, as already noted, presents a closer resemblance to the characteristic Pennsylvanian fauna than any other, would correlate with all of the eastern section to the top of the Kansas Permian. Its failure in the strata which it occupies to measure up to the thickness of the Mississippi Valley section, and the absence from it of some of the modifications found there, would be ascribed to pre-Hueconian erosion. After this episode there was, it might be claimed, a faunal change represented in the Hueconian fauna of the West and in Mr. Beede's red beds fauna of Oklahoma, this in turn being succeeded by the Guadalupian fauna.

Though keeping this interpretation of the facts well in mind, I am at present adopting the more conservative hypothesis—that the top of the Kansas Permian may be as high as the base of the Guadalupian; but that no part of the latter correlates with any part of the invertebrate-bearing beds of Kansas.[1] From this it would follow that if the Guadalupian is equivalent to the Russian Permian then the Kansas Permian is distinctly older, possibly Artinskian, possibly Gschelian. If, on the other hand, the Kansas Permian is really equivalent to that of Russia, the Guadalupian would appear to be a distinct and faunally well characterized series younger than the Permian.

It is well in considering the use of the word Permian for North American strata to discriminate Permian time, Permian conditions, and Permian faunas. Permian conditions, or conditions such as were prevalent in Russia during Permian time, might recur more than once. Indeed, it is safe to say that most conditions are repeated in one area or another many times during geologic history. Permian conditions would give character to the sediments and to the faunas of Permian time. But, while the same peculiarities of sedimentation would presumably be manifested at every recurrence of Permian conditions, the character of the fauna would be partially determined by another factor, the biologic factor. It is conceivable, or even probable, that

[1] By this expression I mean to include the Marion and subjacent formations.

similar conditions acting upon two unlike faunas might produce rather similar results. The resulting faunas might be less diverse than the original ones. This is perhaps particularly true of conditions such as appear to have prevailed in the typical Permian, conditions hostile to marine life, hostile especially to the continuance of specialized types of life, at least of brachiopods.

In the Kansas section we appear to have a single faunal sequence gradually passing to extinction but undergoing some minor modifications in the process. The upper portion of the sequence is the Kansas Permian. We are told by those who are familiar with both, that Permian conditions are manifested in the so-called Permian sediments of the Mississippi Valley. I believe that there is no strictly Permian fauna in that area. The question at issue is: Do the higher invertebrate-bearing beds of the Kansas section represent Permian time? On the assumption that such is the case, a comparison of the evolution of the faunas of the two continents is interesting. Let any one acquainted with our eastern faunas look over Trautschold's monograph on the Moscovian fauna and he would exclaim at once, "This is our Pennsylvanian facies." Let him next examine Tschernyschew's monograph on the Gschelian brachiopods, and he would find that nothing at all comparable is known among the faunas of eastern North America. He would even find that the few Pennsylvanian species which Tschernyschew has recognized among the Gschelian brachiopods are wrongly identified. If he furthermore studies the scattered accounts of the Artinskian and Permian faunas I think, too, that he will find less resemblance between them and the Kansas Permian than has often been supposed.

Apparently there was a basal generalized type of Upper Carboniferous fauna distributed over both continents without any wide difference of facies—the Moscovian of Russia, the pre-Hueconian of western North America, and the early Pennsylvanian of eastern. Then changes occurred which brought about striking and similar modification in the faunas of western America and Russia, the Gschelian of Russia and the Hueconian of western North America. Then again other changes occurred which brought about a third modification, this time restricted to western America, or, at all events, not developed similarly there and in Russia. Meanwhile the fauna of

eastern North America must have remained essentially static until similar conditions, setting in in Perm and in Kansas, eventually extinguished those already moribund faunas, while the intervening faunas, those of western America, remained vigorous and rich. The considerable differences found between the Russian Permian and the Kansas Permian faunas would, according to this hypothesis, be explained as due to the play of like conditions upon unlike organic bases, the pre-Permian faunas in the one region having changed, and those in the other having remained unchanged. But this appears to me improbable. One would hardly expect that the Pennsylvanian fauna would remain static during so long a period in which such important faunal changes were taking place in adjacent areas. Nor would one expect that Permian conditions would be inaugurated simultaneously in two areas so far apart, whose biologic histories are so different, and which were separated by an area having a more or less independent set of faunal phenomena. Finally, if the Kansas Permian is Permian, what is the fauna from the Oklahoma red beds, obtained at a considerably higher horizon, and showing a considerably different facies? It does not seem probable to me therefore that the Kansas Permian and the Russian Permian were contemporaneous.

An extreme interpretation of the resemblances and differences noted in comparing the successive faunas of Russia and eastern North America would result in correlating the Kansas Permian not with the Russian Permian, as in the last hypothesis, but with the Moscovian. In this case the quasi-Permian facies of the upper beds of Kansas would be accounted for as showing the yield of an unlike and older fauna to Permian conditions which arrived on this continent at a much earlier period than in Russia, just as in the previous case the *differences* of the same fauna from the typical Permian would be explained as the opposite or complementary phenomenon, the resistance of an unlike fauna to Permian conditions. Probably the ultimate fact lies somewhere between these two extreme interpretations of the evidence.

I do not wish to appear as having a rooted aversion to admitting the Permian age of the higher faunas of the Kansas section. My position is merely that of a skeptic and the only point upon which I feel justified in assuming the positive attitude of dogmatism is that

the evidence at present is so inconclusive that dogmatism itself would be ill-advised. At present, it is true, the weight of evidence, as presented by invertebrate paleontology, appears to me to be in favor of its pre-Permian age. This view has much of precedent against it, although it has considerable authority in its support. It will be remembered that some half century ago there was a conscious and competitive attempt between a number of invertebrate paleontologists to discover the presence of Permian rocks in our then western states. From this the correlation of the Kansas beds with the Russian Permian took its rise. I am inclined to believe that were the investigation of this subject taken up on its merits from the richer accumulations now available, and not compromised by this early rivalry, few if any would think of separating the upper formations of the series from the lower, or, if a separation were thought of, the divisions would be held rather to rank with the subdivisions recognized in the Mississippian than co-ordinate with the larger groups such Mississippian and Pennsylvanian.

At all events, it appears to me from such evidence as I have seen, that the Russian Permian represents peculiar, one may perhaps say abnormal, conditions which were probably local or regional in extent. That Permian time is represented by our sediments seems undoubted; that Permian conditions prevailed here is attested by good witnesses; that Permian conditions occurred here in Permian time seems to me open to question, and that any of our known faunas present the authentic Permian facies, I do not believe. Consequently the propriety of employing the term Permian in the geology of North America seems to me decidedly doubtful, at least in so far as the evidence of invertebrate fossils is concerned. It would be better, I believe, to use the term Permian wherever the Permian fauna can be traced and no farther; to use the term Pennsylvanian wherever the Pennsylvanian fauna can be traced and no farther; to use the term Guadalupian wherever the Guadalupian fauna can be traced and no farther; but, if, for instance, it could be shown that for all their faunal differences the Gschelian and Pennsylvanian were contemporaneous, to use for both the same name, whether Pennsylvanian or Gschelian, would be to obscure and gloss over facts of biology, climatology, and possibly geography, fully as important as that of chronology.

THE UPPER PALEOZOIC FLORAS, THEIR SUCCESSION AND RANGE[1]

DAVID WHITE

VII

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STRATIGRAPHIC VALUE OF LAND PLANTS

Diastrophism and floral changes.—The terrestrial plant is inseparably dependent on the conditions, not only of the soil and the water, but also of the air from which it derives an important part of its substance. Any change, therefore, in the climatic, terrestrial, or water conditions of its environment directly affects the plant and causes morphologic changes to a greater or less degree, the greater plant variations corresponding usually to the greater environmental changes. The great floral revolutions of geologic history are connected with the great diastrophic movements.

Sensitiveness of land plants to complicated environment.—The land plant, being essentially without the power of locomotion except by accidental dispersion of its progeny, is most vitally susceptible to changes in composition, temperature, etc., of its environmental elements. Accordingly it constitutes a most sensitive indicator of changes in these elements. The more highly organized the type the greater, in general, is its value as evidence either for identity of

[1] Published by permission of the director of the U. S. Geological Survey.

environment or for altered conditions. It must be admitted, however, that in the interpretation of the environmental criteria afforded by fossil plants, relatively little serious study has been given to anything other than climate. The ecology of the fossil floras is a new and almost unexplored department of paleobotany, though splendid work along certain lines was begun by Grand'Eury. The results of differences in soils or in altitude have received little attention. In general the conditions of fossilization naturally presuppose the origin of the vegetal forms at an elevation not far from that of the water-level beneath which they have, in most cases, been preserved, though here and there certain types have been regarded as drifted from higher altitudes.

THE DEVONIAN FLORAS

Probable origin of land flora in Devonian.—From the paleobotanical standpoint no period within the existence of land floras is of such imminent interest and yet is so little known as the Devonian. This fact is no doubt due mainly to the relative rareness of indubitably botanical material, its usually fragmentary condition, or its partial obliteration through metamorphism. Yet the Devonian period probably covers the early development, if not the actual beginning, of terrestrial plant life on the earth. It witnessed the origin of ferns, scouring rushes, Lycopods, and Gymnosperms, including the earliest relatives of the conifers. It is supposed to have given birth to the Pteridosperms, a group of seed-bearing ferns (Cycadofices), standing in the gap between the ferns and the Cycads.

Features of early land plants.—The development in early Devonian time of flat land surfaces and low coasts whose bays were bordered by broad marshes intermittently covered by brackish or fresh waters was most favorable for the nearly simultaneous development of a terrestrial habit in some of the highly varied types which then populated the seas. On some accounts it seems permissible to suppose that the ancestors of the land plants were amphibious, perhaps growing where exposed only at the recession of the tide. It is, I believe, probable that these early plants were but sparsely foliate, their leaves being either spinoid or very small, slender, and delicately thin. The latter were probably dorsally rolled at first during the

intervals of exposure to the air. The stomatiferous surfaces may have been very small for a time, and the stomata of periodic function only while the greater part of the carbonic-acid gas to serve as plant food was still drawn in the old way from the richly charged waters. The expansion of a proper leaf and the production of an aërial system of transpiration were presumably gradually evolved as the plant became weaned from its subaqueous habitat and accustomed to gain its food from an atmosphere which, it may be, was then better adapted to the nourishment of the emergent amphibian. However this may be it is fairly clear that the early representatives of the dominant Devonian types were of limited foliar expanse. Cuticular transmission of gases is still observed in the living ferns and Lycopods, the latter being far less susceptible to carbon-dioxide poisoning than are the higher plants.

It also appears that to support their weight in air a reinforced cuticle, later developed as a very thick and complicated cortex, was made to serve until a woody axis and, eventually, secondary wood should be fully produced by their descendants. From the characters of some of the fossils it seems probable that, unable to stand alone, they sprawled or clambered about on the ground or on other plants.

The mode of occurrence of their fossil remains usually in fresh or brackish water lagoonal or estuarine deposits, which are frequently ripple-marked, or even sun-cracked, may be regarded, though not without caution, as pointing out the conditions of their earliest habitats.

MIDDLE DEVONIAN

Characters.—The first Paleozoic land flora sufficiently known to make it eligible to the series of correlation discussions is that of the Middle Devonian.

This flora, whose apparent meagerness is perhaps due mostly to meagerness of information, is of strange and forbidding aspect. Its most characteristic types are Psilophyton, Arthrostigma, and Rhachiopteris of Dawson. It is also marked by the presence of Protolepidodendron, a primitive forerunner of the great lycopod group and, before reaching the Portage we find added Archaeopteris, together with the curious Pseudosporochnus, which may supply the missing fronds to the defoliated Caulopteris-like stems fro m Ohio and New York.

Place of origin.—Though eastern America has contributed most to our knowledge of this flora, it is probable that either the estuaries of northwestern Europe or the Arctic regions offered the conditions most favorable for its development. It extended both east and west in a high degree of unity. For example, the flora which occurs in the "Chapman" sandstone in Maine, and which is present in the gulf region of Canada, is largely the same as that of Scotland, at Burnot in Belgium, or in the Lenne shales of the Rhine Provinces. The flora from Barrande's *H-h*, stage at Hostim in Bohemia is nearly counterfeited in the upper Middle Devonian of New York. The route of migration between Europe and America was presumably by Arctic lands beyond the North Atlantic. Nothing that can be called a land flora is yet known from the Middle Devonian of the Southern Hemisphere.

UPPER DEVONIAN

Floral characters.—Evolution of forms and the advent of new types mark the Upper Devonian flora, which bears no evidence of any great climatic separation from the preceding. Pseudobornia, perhaps first of the Protocalamariales, Dimeripteris, Leptophleum, Barrandeina, and Barinophyton are characteristic. It is pre-eminently the stage of Archaeopteris. The Protolepidodendreae are developing along divergent lines to Cyclostigma and to the Carboniferous Lepidodendron, while Archaeosigillaria makes its rare appearance.

Place of origin and migration.—I am strongly inclined to believe that this flora received its greatest contribution from eastern America, or, perhaps, from the Arctic regions; in either event its migration was probably over boreal land; for it extends with remarkable identity from Pennsylvania to southern Europe and is partially present even in Australia. *Archaeopteris obtusa* and *A. sphenophyllifolia* of Pennsylvania and New York are *A. archetypus* and *A. fissilis* of Ellsmere Land, Spitzbergen, and the Don; while Barinophyton, a unique type from New York, Maine, and Canada, extends to the British Isles, Belgium, Queensland, and Victoria, where also is found *Leptophloeum rhombicum*, another American plant.

The Devonian woods present no annual rings to bear evidence of seasonal changes in temperature or intervals of prolonged drought.

THE CARBONIFEROUS FLORAS

MISSISSIPPIAN ("LOWER CARBONIFEROUS")

Characters.—The step from the Upper Devonian flora to that of the Mississippian ("Lower Carboniferous") is marked by a floral contrast which, in some regions, is unexpectedly sharp though the warping of the Devonian floor to form the new Carboniferous synclines and the contraction of the seas naturally premise distinct climatic as well as other environmental changes. The new flora which lived in the restricted basins of the early Mississippian consists of Triphyllopteris, the broad, large-pinnuled Aneimites, the linear (*flaccida*) type of Sphenopteris, Cyclostigma, Eskdalia, and the acuminate Lepidodendra chiefly of the *corrugatum* group.

Lowest stage—Pocono.—The early Mississippian was a time of sea expansion; and in a number of distant areas, such as the northern part of the Appalachian trough, northern Alaska, the eastern Arctic, Scotland, and southern Siberia, the conditions at this moment were favorable for the formation of considerable coals.

Source.—Since the vegetation was presumably most luxuriant in these regions of coal formation, and since greatest evolution of forms attends most rapid and luxuriant expansion of a flora, we are perhaps safe in supposing that these are probably the regions of evolution of the flora as a whole.

Regional differences.—In this connection it may be noted that, either on account of land or marine barriers, or because the climatic conditions throughout the northern hemisphere may at the outset have been less uniform than in the preceding epoch, the different areas exhibit more or less distinct local floral differences. Thus in the Pecono of West Virginia and Eastern Pennsylvania where Triphyllopteris and the *corrugatum* type of Lepidodendron are almost without competition, the former achieved a remarkable differentiation far surpassing that known in any other area. In Nova Scotia, on the other, hand, the Horton series, which I regard as practically contemporaneous with the Pocono, contains the same Lepidodendra, accompanied, however, by Aneimites instead of Triphyllopteris. In both these regions the formations are in close relations with the Upper Devonian—in fact, probably in continuous sequence at one point or another. But the Pocono flora is apparently nearer to the Arctic

Alaskan where the same linear-lobed Sphenopteris forms are also present; the Nova Scotian affiliates more closely with the eastern. All the genera mingle in Arctic Europe and in Siberia, where Cyclostigma, probably of Arctic birth, has a good development. The Pocono flora may have connected by a more northern route with Europe, where Triphyllopteris sparingly mingles with the Horton Aneimites, which presumably migrated by the Northeast Arctic land bridge. It is possible, however, that some of the regional differences, especially differences in species, are due to lack of exact synchronism in the plant beds of these remote regions.

Middle Mississippian flora.—The basal Carboniferous floras are largely replaced in the middle Mississippian by a plant association which is more varied and of very different aspect. Where conditions were favorable for plant growth and preservation we find a flora essentially consisting of Rhacopteris (of Schimper, including Rhodea of authors), Cardiopteris, Asterocalamites (=Bornia), with *Lepidodendron volkmannianum*, and *L. veltheimianum*, accompanied by a gradually increasing group of Sphenopterids.

Source and distribution.—The middle Mississippian flora probably had its greatest development among the islands and estuaries of western Europe; at least it is best known in that region. From there it seems to have extended almost homogeneously to the eastward into Siberia and to the southeast, either through the Balkans, Persia, and the Himalayas (linking together its discovered occurrences), or possibly by a more southern route, to South Africa and Australia where the flora was largely identical with that in Siberia. The flora at Cacheuta, in Argentina, which though small is mainly composed of European species, presumably traversed the same route as that later followed by the Gangamopteris flora—that is the "Gondwana land." The middle Mississippian flora of the Appalachian trough is but little known, and for the most part is unpublished. Though less closely bound to that of Europe than are the corresponding Pennsylvanian floras its genera and a number of its species are present in the basins of Europe. I may add that the Megalopteris-bearing beds along the Mississippi River in Illinois, long ago credited to the Chester, are of upper Pottsville age.

Moderate uniformity of climate.—The members of this flora do not

attain the gigantic proportions nor the specific differentiation of their Carboniferous successors; yet the relative homogeneity and the great radial distribution of this flora argue for the absence of distinct climatic zones in the recent sense while the apparent lack of annual rings, so far as the woods have been specially examined, is opposed to the idea of seasonal changes.

Upper Mississippian. Probable greater severity of climate.—Our knowledge of the flora of the uppermost part of the Mississippian is too insufficient, both as to its composition and its geographical distribution, to permit any very definite conclusions as to its province and climatic environment. Some at least of the plants exhibit a limited foliar expansion and semi-coriaceous character suggestive of conditions far less favorable for growth than in the Pennsylvanian ("Upper Carboniferous"), or even in the early Mississippian. They seem to forewarn us of the great floral change which was, perhaps, already in progress. From this highest stage may have come *Dadoxylon pennsylvanicum*, the only wood from the American Carboniferous which appears on authoritative testimony to show annual rings, but whose geologic age is unfortunately recorded merely as "Carboniferous." Also it is possible that the *Araucarites tchihatcheffianus*, from western Siberia, said to have been found in the Carboniferous limestone series, may belong to the same horizon. The occurrence of severer climatic conditions with seasonal changes within upper Mississippian time is provisionally admissible; but it is probable that a radical climatic change attended the post-Mississippian elevation, the maximum variation being presumably marked by the climax of the uplift. The paleobotanical revival which set in at the beginning of the Pennsylvanian is known to all. Even in regions of supposed continuous Mississippian-Pennsylvanian deposition the contrast between the older and the younger floras (which do not really come in contact), is very strongly marked.

PENNSYLVANIAN ("UPPER CARBONIFEROUS")

The Westphalian

Environmental changes.—Following the retirement of the sea from great areas at the close of the Mississippian ("Lower Carboniferous"), the new land surfaces were warped into new forms, with the produc-

tion of additional as well as more complicated synclines. In these at first greatly restricted basins the sea began a great readvance, attended by the subsidence and deformation of the new basins under loading. These changes were most active during the Pottsville, the lowest of the American Pennsylvanian series. The new climatic and terrestrial conditions were most favorable to the extraordinary growth and differentiation of the plant life which spread across broad base-level plains and over the marshes and lagoons that flanked its long inland-reaching estuaries.

Appalachian deposition.—In the Appalachian trough the basin in earliest Pottsville time was confined to a very narrow estuary extending from the anthracite region of northeast Pennsylvania southward to Alabama where it became confluent with a small lobe of the sea extending northward toward southern Illinois and Indiana. Subsidence under loading was most rapid, with successive periods of sea advance to the north and west during all Pottsville time, at the close of which the water-level may have proximated its greatest Pennsylvanian extent; at least it exceeded the present limits of the coalfields.[1] The enormously expanded water-level of the Allegheny formation attended a westward migration of the axis of deposition, probably with the development of minor subordinate basins. Slight warping occurred during the period, especially to the southward, so that the connection with the Eastern Interior basin presumably migrated northward into the Kentucky region, foreshadowing the probable exclusion of the sea from the southern area of the present Appalachian coalfield during later Conemaugh and Monongahela time.

Rapid Evolution. Floral characters definite, with many short-lived genera in early Pennsylvanian.—The most rapid evolution of the Pennsylvanian flora occurred during Pottsville time, though the generation of new forms continued at a slower rate into the Allegheny, which, together with the Pottsville, approximately represents the Westphalian or Muscovian in North America.

The Westphalian is the period of Cheilanthites, Mariopteris, Diplothmema, Crossotheca, Eremopteris, Palmatopteris, Lonchopteris, Megalopteris, Lesleya, Neriopteris, Bothrodendron, Ulodendron, Lepidophloios, and Whittleseya, besides a number of genera repre-

[1] *Bull. Geol. Soc. Amer.*, Vol. XV (1904), p. 267.

senting filicoid types of fructification. One-half of these genera scarcely, if at all, survive the Pottsville. Three or four only outlive the Allegheny. The Westphalian witnessed the maximum development in Sphenopteris, Neuropteris, and Alethopteris, and of the great Lycopod group. It is pre-eminently the stage of the Cycadifilices.

Remarkable distribution of identical species.—The intercontinental distribution of the Westphalian plants is probably less remarkably uniform than is generally stated. The examination of the floras shows minor differences between the floras of different basins, as, for example, freshwater or marine basins in the same country, though many of these differences disappear as additional material is collected. Also different areas in the same basin, and, similarly, different horizons in the same basin may show predominances of Lycopods, or ferns, etc., or the apparent absence of certain genera. But as between the larger provinces, and taking the flora as a whole, from continent to continent, the number of genera not common, for example, to Europe and America, is so small as to excite special interest. The proportion of identical species is so large as to necessitate an extraordinary lack of barriers to the freest migration. The flora of the basin of Heraclea in Asia Minor[1] lends itself to ready correlation, stage by stage, with three corresponding formations of the Pottsville in the Appalachian trough; also, of the 33 species reported by Zeiller in a collection from the Westphalian of the Djebel-Bechar region of Persia, 25 are present in the Pottsville of the Appalachian trough.

The uniformity of distribution of the Westphalian flora complicates the geographical question of its origin. Taking therefore as most reliable the evidence of first appearances, we may note that Cheilanthites (including portions of Pseudopecopteris and Sphenopteris), Mariopteris, Eremopteris, Neuropteris, Alethopteris, and perhaps Pecopteris, were more highly differentiated in America, though Sphenopteris experienced a perhaps greater development in Austria and Bohemia. In Europe the Lycopods appear to have had greater advancement. Also, Cingularia, unknown outside of the freshwater basins of Germany, and Lonchopteris, largely confined thereto, have not yet been found in North America; while the unique genus Neriopteris is still unknown in Europe. On the other hand, the rare

[1] *Jour. Geol.*, Vol. IX (1901), p. 192.

genera, Lesleya, Megalopteris, and Whittleseya, apparently originated in America whence they spread northeastward. The same is true of the lower Pottsville Phyllotheca, which appeared a little later in Heraclea, and finally, in a new group of forms, became somewhat characteristic of the Gangamopteris flora of "Gondwana land." On the whole, therefore, it is probable that the Westphalian flora is the joint contribution of the lagoonal—i. e., coal-forming—regions of western Europe and eastern America. Free inter-communication was almost certainly by an Arctic land bridge, possibly by way of a Greenland-Scandinavian shore connection. The general regional distribution of the Pennsylvanian floras is shown in Fig. 1.

The Stephanian

Conditions of deposition and probable equivalents.—The Stephanian or Ouralian (including the Gschellian) of Europe dates from the Hercynian uplift. Prior to this movement the sea had reached its maximum extension in the coalfields of the northern hemisphere. The Hercynian thrust caused its practical expulsion from the old synclines of western Europe and the creation, especially to the southward, of new basins, mostly of fresh or brackish water, to which were transferred the scenes of coal-formation. In America the line between the Westphalian and Stephanian is not yet accurately drawn, the fossil floras being not studied in sufficient detail. In view, however, of the paleobotanical evidence indicative of a point near the Allegheny-Conemaugh boundary, I, personally, am inclined to regard the formation of the Mahoning sandstone (conglomeratic), the changed sedimentation of the Conemaugh formation, the probable upwarp of the southern Appalachian region which later resulted in the exclusion of the sea from the northern area also, and the consequent climatic changes, as due to the same great orogenic influence. Accordingly I would provisionally place the greater part, if not all, of the Conemaugh together with the Monongahela in the Stephanian.

The final exclusion of the sea from the Appalachian trough appears to have occurred soon after the deposition of the Ames limestone, near the middle of the Conemaugh, since, according to reports, only fresh, or possibly brackish water mollusca occur in the higher terranes.[1]

[1] I. C. White, *Report IIA*, Geol. Surv. W. Va., p. 622.

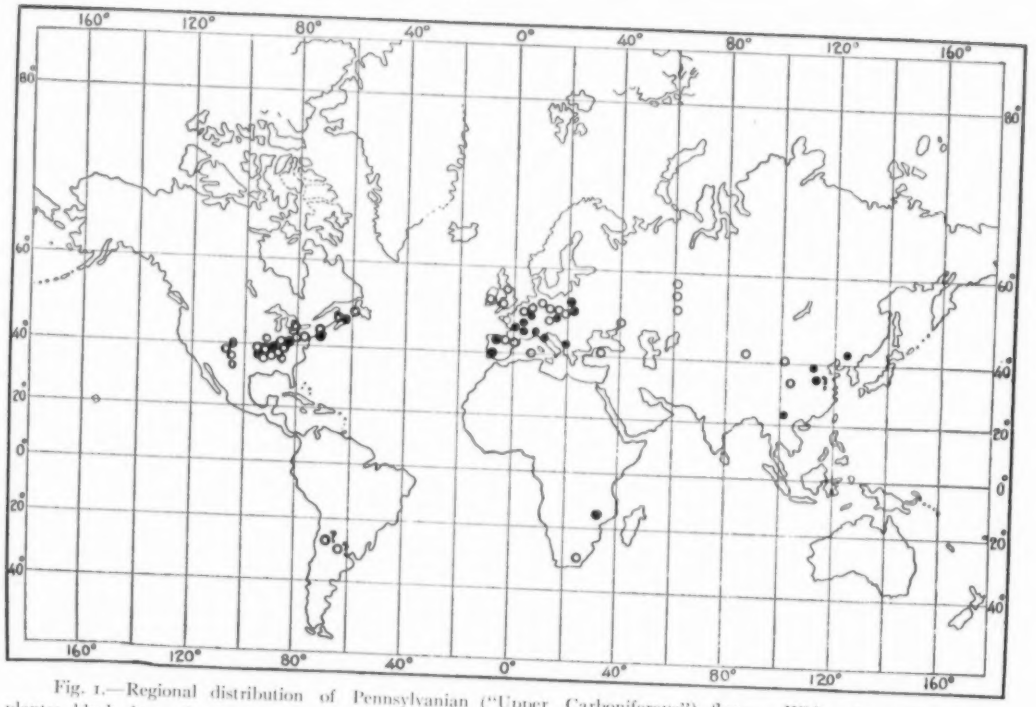


Fig. 1.—Regional distribution of Pennsylvanian ("Upper Carboniferous") floras. White rings = Westphalian plants; black rings = Stephanian plants.

It is probable that the Monongahela was never deposited in the southern Appalachian region, from portions of which the Conemaugh may also have been absent, the red oxidized sediments of the latter being in part derived, I believe, from the eroded unconsolidated older Pennsylvanian to the southeastward.

Floral characters.—The Stephanian is marked by the great development of Pecopteris, Callipteridium, and Odontopteris of the true type. It witnessed the nearly complete disappearance of Alethopteris, Sigillaria, and Lepidodendron. Neuropteris of the large-pinnuled forms enters its period of decadence. Before its close appear the first representatives of Callipteris, Walchia, Taeniopteris of the simple type, Pterophyllum, Zamites, and Plagiozamites, all characteristic of the Permian or later periods.

In eastern America, where the relations of land and water were but gradually altered and the sedimentation was continuous, the passage to the Stephanian flora has no line of sharp paleobotanical demarkation. The change appears to be gentle and the older forms drop out more slowly. In Europe, on the other hand, the contrast is a little sharper; the old types disappear more abruptly and many new ones take their places. A number of these new types have not yet been found in the Permian of this country. Among these are the four Permian coniferal and cycadalean genera above mentioned.

Source and distribution of the flora.—It is clear that the new elements of our Stephanian flora are chiefly, at least, of European origin, the plant life there having been directly influenced by the important physical changes to which it was immediately subjected. The various exotic types migrated to North America, probably, along or near the general route traversed by their Westphalian predecessors. Also, since the Stephanian flora of the American basins seems to afford no evidence of a rapid or strongly pronounced climatic alteration, it becomes fairly probable that the more abrupt plant changes described in western Europe were induced chiefly by the sweeping orogenic effects of the Hercynian movement, rather than by a great climatic change of world-wide extent. This does not, however, preclude a moderate but far-reaching modification of climate, in which changes in the atmospheric composition may have played a subtle if not important part. It seems hardly possible that the tremendous

amounts of carbon then being stored away in the coalfields as the result of plant extraction from the air could have failed to produce some effect on the atmospheric content of CO_2.

Though the Stephanian flora has less unity in its distribution than had the Westphalian, it is nevertheless remarkable for its geographical range. The flora reported by Zalessky[1] from the Yen-tai mines near Mukden in Manchuria embraces eight species, seven of which are found in western Europe, while six are present in the Appalachian trough. Or, looking southward, at Tete on the Zambesi in southern Africa, we find that all of eleven species reported by Zeiller are present in Europe and nine or ten, about 80 per cent., in America also. In harmony with these facts we find but slight traces of annual rings in the woods of the Stephanian, either in Europe or in America. This is the more noteworthy because the date of the Gondwana-land glaciation has been referred by various geologists to the Stephanian.

THE PERMIAN FLORAS

Floral characters.—The coming of the Permian is characterized not only by orogenic movements in the eastern hemisphere, but also by indications of increasing climatic differences. The first paleobotanical effect of these is the extinction of nearly all characteristic Carboniferous types, except in Pecopteris, Cordaites, and Neuropteris, the latter, however, disappearing nearly completely by the close of the Autunian or lower stage. They are replaced by varied forms of Callipteris, the lingulate Odontopteris and the ribbon-like Taeniopteris, together with expanding gymnospermous types, such as Walchia, Dicranophyllum, Doleropteris, Psygmophyllum, and Ginkgophyllum. Later, in the Saxonian, or Middle Permian, Voltzia, with the thick-leaved Equisetites, appears while more of the older types go out; and in the Thuringian, or Zechstein (Upper Permian) Rhipidopsis, Araucarites, Gomphostrobus, Voltzia, and Ullmannia, become the characteristic genera, while Pecopteris, dominant in the Stephanian, has nearly vanished. Though lacking the abundant Cycad and Cladophlebis-Asterocarpus elements, the Upper Permian is in many respects transitional to the older Mesozoic flora.

The Gangamopteris or lower Gondwana flora.—Meanwhile in the South a new flora, the Gangamopteris flora, or so-called Glossopteris

[1] *Verh. Russ. K. Min. Gesell.* (2), Vol. XLII (1905), p. 485.

flora, has arisen in the wake of retreating ice, though it is not really a glacial flora. It probably originated in a great region, the "Gondwana land" of Suess, from which the Stephanian flora had been more or less completely expelled by the rigorous climate, and to which it had not yet been able to return, presumably on account of either temperature or isolation.

The dominant characteristic types are Gangamopteris, Glossopteris, and its rhizome Vertebraria, Neuropteridium, Noeggerathiopsis, Phyllotheca, Schizoneura, Ottokaria, and Derbyopsis. The distribution and the relations of this flora to the Northern or Cosmopolitan flora have already been discussed in this journal.[1] The geographical extension of this flora in Paleozoic time, as also the distribution of the northern or cosmopolitan Permian flora, are shown on the Permian map, Fig. 2.

Distribution.—The uniformity of the Gangamopteris flora is so nearly complete as emphatically to indicate freedom of migration between all the areas in which it dominated; but whether Australia communicated with South Africa by way of India and Arabia, or by connection through an Antarctic land mass is a matter of opinion. The former is perhaps more probable. South America was almost certainly made accessible either to Africa or Australia by route over Antarctic land.

Gondwana climate.—The Gondwana climate following the glaciation was not too severe for the early return at distant points of a few of the presumably hardiest representatives of Psaronius, Sigillaria, Lepidophloios, and Lepidodendron, and at a higher stage, Voltzia Psygomophyllum, and Pterophyllum, both in Africa and South America. The early return of a climate not so widely different from that of the western Permian is further shown by the fact that though the early Gondwana woods found in beds more or less closely associated with the bowlder beds in Australia and South Africa show annual rings indicative of sharp seasonal changes, the woods from the higher portion of the series in South America show nearly continuous growth with but slight trace of seasonal differences.

Ability of types to mingle in later Permian and early Mesozoic environments.—This amelioration of temperature harmonizes, firstly,

[1] *Jour. Geol.*, Vol. XV (1907), p. 615.

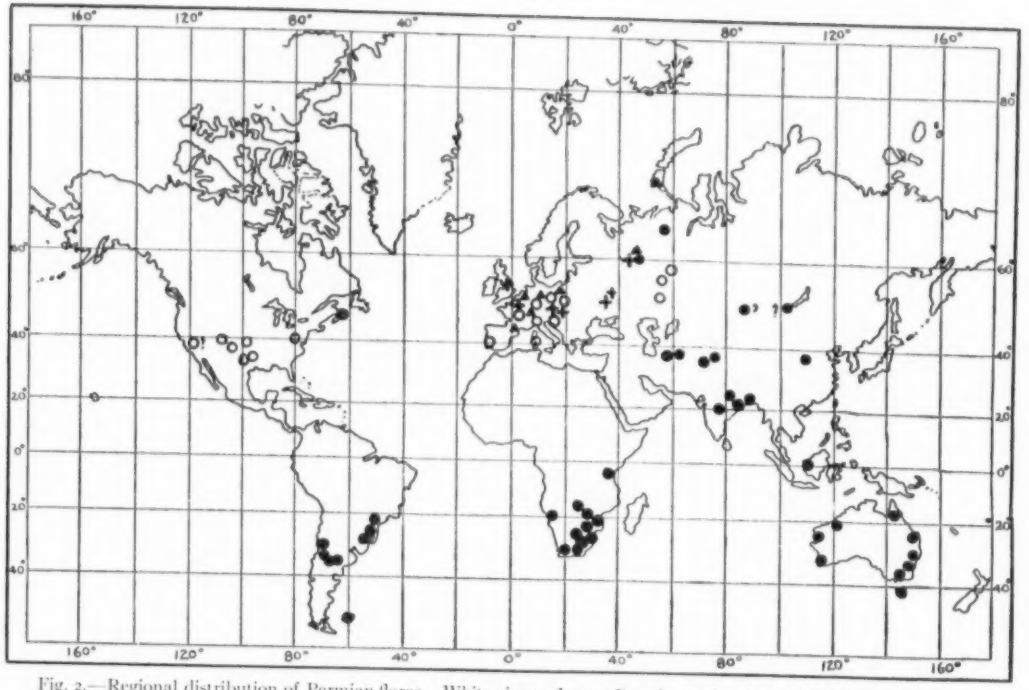


Fig. 2.—Regional distribution of Permian floras. White rings = Lower Permian; triangles = Middle Permian; crosses = Upper Permian; solid rings = Gondwana flora.

with the return of some of the northern types to portions of Gondwana land, and, secondly, with the fitness of some of the Gondwana types, especially Glossopteris, Phyllotheca, and Noeggerathiopsis, not only to join with Walchia and Callipteris in the Zechstein flora of northern Russia, but later to meet with Podozamites, Ctenophyllum, Cladophlebis, Clathropteris, and Dictyophyllum, under the mild climatic conditions of the early Mesozoic. Glossopteris, perhaps most adaptable of the older Gondwana types, was able to reach as far as the supposed Rhetic of Tonquin where it is last seen.

Glaciation.—It appears, therefore, that the interval, or better the *intervals*, of glaciation in Gondwana land were of relatively short duration as compared to all Permian time, though the thickness and distribution of the glacial deposits indicate a magnitude far exceeding that of Pleistocene glaciation. At the same time it seems improbable that refrigeration could have occurred in so many regions of the southern and eastern hemispheres, even approaching the equator, without some corresponding, though unequal, changes of world-wide extent. Concerning this very important point, the evidence is quite inconclusive and the opinions varied.

American Permian types derived from Europe.—If we compare the plants of eastern America with those of western Europe we find the greater changes in Europe where the extensive orogenic movements and attendant shifting of basins of deposition doubtless stimulated the evolution of the Permian flora. On the other hand, in the Appalachian trough, where environment was but little affected by orogeny, and where sedimentation was uninterrupted, there is only gradual change, many of the Stephanian types persisting far up in the Dunkard formation. The relatively few species characteristic of the European Permian which occur in the Dunkard, and which were not able to conquer the older flora under the conditions then existing, are clearly migrants from western Europe. It must be noted, though, that both West Virginia and Kansas exhibit new generic types, the products of local conditions, that have not been found outside of these regions. On the other hand, Walchia, which is present in Kansas and New Mexico has not yet been discovered in the Appalachian trough though it is present in the Nova Scotian basin, which seems to have been in closer touch with Europe at this time. The floral

changes in the western American areas, which are more pronounced than in the Appalachian trough, may be due either to changed physical conditions consequent to nearer and greater orogenic movements, or possibly to position nearer to the region of Gondwana glaciation. In our trans-Mississippi region the contrast between the Permian and Stephanian floras does not seem so sharp as that between the Ural flora and those, for example, of the fresh-water basins of France or England.

Greater contrasts in eastern Europe.—In France and in the Appalachian trough the early Permian floras are to a large extent identical, thus indicating continued freedom of intercourse. Also the woods present obscure rings or none at all. But in Kansas and Texas annual rings while still but slight are increasing in distinctness though many of the associated plants have a European distribution.

The plant fragments from the Permian of Nova Zembla are quite too insufficient to support the hypothesis of a far-northern route of intercontinental migration, or even to show that the climate of western Europe extended so far north.

Ural Mountains on western edge of a great climatic zone.—Indeed, on the contrary, the great scarcity of true Neuropterid and Pecopterid elements, the great development of Psygmophyllum, and the remarkable phases of Callipteris observed even in the Artinsk of the Ural region indicate, in my judgment, either temporary isolation or an appreciable difference in climatic conditions. At the same time the somewhat unique forms of Odontopteris are not without representation both on the central plateau of France and in the Wichita of Texas. This testimony of migration is supported by the supposed land relations, which, if Lapparent is correct, should have been particularly favorable for such a migration during portions of Permian time.

Extension of Gondwana flora into northern Asia.—Eastward of the Ural Mountains the floras of the Altai and headwaters of the Yenesei and in northern Mongolia, though provisionally referred to the Permian on account of the presence of Rhipidopsis, mingled with other types, including some of Gondwana facies, are possibly wholly lacking in specific types characteristic of the Cosmopolitan Western Permian. Though the stage of these plant beds is not yet fixed on

account of the strange character of the flora, I am inclined to regard the peculiar floral association as due to the extension of the early Gondwana climatic influence into north-central Asia and the subsequent isolation of the flora from western influences. This theory is supported by the presence of the older Gondwana flora in the coalfield of Shensi in China. On the other hand the floral differences between the Ural and eastern localities may be due to geographic position of the latter in the interior of the great Asiatic continent while the Ural flora which has more elements in common with the western world is located on the west coast of this continent.

The contrast is certainly not due to mere latitude, nor can it be credited wholly to aridity; for the eastern plants are associated in great series with coals in each region. A few stray wood fragments of uncertain location and age appear to offer slight evidence of seasonal changes, but the criteria deserve careful re-examination both as to this point and as to the geological horizon of the material described.

It would be most interesting to know to what extent the plant life of Permian time on the west coast of North America was influenced by the Gondwana glacial climate and as to how far it was allied to the older Gondwana floras.

The sharp contrast between the Chinese Gondwana plants and the floras of the very latest Stephanian in the same region involves a pronounced break either in climate or in time in that quarter of the globe. Probably both are concerned. The most satisfactory illumination of the stratigraphical and paleontological history of this period will probably be found in China or southern Siberia.

"PERMO-CARBONIFEROUS CLIMATES"

Climate of the Carboniferous.—The climate of the Pennsylvanian ("Upper Carboniferous") as viewed in perspective was mild and relatively humid, and, above all, equable over the greater part of the earth. It was moderate in temperature, not tropical, possibly not even subtropical, but, during the Westphalian at least, always and everywhere equable. It was truly temperate. The criteria which may be interpreted in support of this generally accepted proposition include:

1. The tremendous size and great height of the types, and their rank foliar development, indicating favorable conditions of environment and vigorous nutrition.

2. The succulent nature of many of the forms, the large size of the vessels and cells and the relatively great proportion of soft tissue, all indicating rapidity of growth in a moist, mild climate.

3. Spongy leaves suggestive of a moist atmosphere, and abundant and large intercellular spaces, as in the Lycopods, pointing to rapid moisture loss; also water pores for disposal of excess of moisture.

4. Stomata placed in grooves, as in the Lycopods, as if to prevent obstruction by falling rain.

5. Absence of annual rings in the woods; hence absence of marked seasonal changes.

6. The analogies of the present day show that aërial roots, so prominent in many of the Carboniferous types are characteristic of moist and tropical climates; that the nutrition—i. e., the decom position of CO_2—is most rapid and the consequent growth also greatest and most rapid where the light is not too strong; that the ferns and Lycopods, so abundant in the Paleozoic, usually avoid bright glare. The same types are able to withstand larger amounts of CO_2 with benefit to themselves.

7. The nearest living relatives of the Paleozoic vascular Cryptogams reach their greatest size in humid and mild or warm climates. The successors of the marratiaceous, and gymnospermous types are now mostly confined to tropical or subtropical regions. The cycadalean stock, now characteristic of the same zones, was actually present in the upper coal-measures.

8. The formation of great amounts of coal indicates a rank growth, but in a temperature not so warm as to promote decay beyond the limit of rainfall protection.

9. Living nearest representatives of Paleozoic fishes now inhabit the estuaries of warm countries; while the nearest relatives of the Carboniferous insects are now found in mild and moist habitats.

10. The most forcible argument, after all, for an equable and uniform climate lies in the extraordinary geographical distribution of the floras in relative unity over the face of the earth. Humidity must naturally have attended such equability, extending, without

distinct terrestrial climatic zones, possibly completely into the polar regions.

Some of the criteria above mentioned are susceptible of different interpretations; but taken collectively they appear to admit of but one conclusion. Whether or not we admit that climatic changes may be caused by reasonable or practicable changes in the amount of carbonic-acid gas in the air it is certain that in geological times the vegetation of the earth must have been more or less influenced by the constitution of the atmosphere from which the plant derives so important a part of its real food.

Gradual loss of uniformity of climate, with brief glacial interruption in Permian.—As has already been indicated the Westphalian probably witnessed the greatest extension of uniformity and equability of climate over the earth. In the Stephanian the flora is hardly so homogeneous, though the world-climate appears still to have been so equable as to allow free migration of the larger part of the flora from a moderate latitude on one side of the equator to the opposite without encountering seriously obstructive seasonal changes. In the Permian the regional distinctions between the floras are much clearer; and presently climatic zones, and consequently botanical provinces, are recognized. Yet, about the North Atlantic the climate of the Lower Permian was still relatively uniform so that moderately free migration of the floras without the development, so far as we know, of pronounced annual rings, took place in the Autunian of France, the Permian of Prince Edward Island, the Dunkard of southwestern Pennsylvania, the Chase of Kansas, and the Wichita of Texas.

Red beds and climate.—It will be remembered that the period now considered is characterized in western Europe, England, Eastern Canada, the Appalachian trough, and the Western Interior basin, by the deposition of red beds which in some areas carry deposits of gypsum, etc., and which are generally regarded as laid down under an arid climate. Viewing the matter from the paleobotanical standpoint, we may ask whether equability and uniformity of climate, such as is shown by the fossil floras, is compatible with aridity in latitudes so high as northern England and the Gulf of St. Lawrence. If all the regions of Permian red-bed deposition were arid it would seem that humidity could not have been essential to equability of climate.

Coal-formation in Permian.—The lower Permian of Germany, France, Russia, and Pennsylvania, is commercially coal-bearing, while the Permian red beds of Kansas and Texas carry thin coals. Professor C. A. Davis informs me that in the United States today the formation of peat, the first stage of coal, is practically confined to the zone having twenty inches, or more, of rainfall.

Flora in red beds not perceptibly different from that in other sediments.—The plants in the Monongahela and Conemaugh do not seem to differ in kind whether the series are gray and limestone-bearing in Pennsylvania, or red and nearly devoid of limestones seventy-five miles to the south in West Virginia; except that although sometimes fairly abundant, they are very difficult to find in the red shales because the carbon of the plants is almost or entirely gone, as the result of destructive decomposition, only impressions of the leaves being left. Is it not possible that, in some instances, the causes of red-bed deposition lie to a large extent in relatively slow subsidence of the basin, and in differential warping to permit exposure, with some redeposition and dehydration? It is probable that there was aridity in certain regions and during certain intervals of the Permian; but there was evidently enough moisture to produce most extensive glaciation, and, later, to promote the formation of coals over broad areas in the great fresh-water Gondwana series laid down on the continents of South America, Africa, and Asia. The beds with the Gangamopteris flora are in most regions coal-bearing, usually commercially.

Date of glacial episode.—If one looks for climatic fissures, or dislocations into which to fit the relatively brief episode of Gondwana glaciation it is difficult either in western Europe, or in America, to find an opening between the base of the Westphalian and the top of the Lower Permian in which it may be fixed. It is true that, in most sections, we have intervals in which no plants are found; and, further, the lesson of Pleistocene deposition shows what sweeping climatic changes may occur and recur within a relatively insignificant thickness of strata. Yet, while the gap is often large enough in stratigraphical view, the plant-sequence so tightly closes it as to preclude a possible very distant exile of the flora for a time. We may therefore conclude that the glacial episodes probably occurred at the time of one of the orogenic movements; and, if so, preferably at one marked by the most

striking floral changes, since the effects of so important a climatic event must have been widespread.

If, therefore, the glacial interruption did not occur at the close of the Mississippian, as Bodenbender seems to see it, we may, I think, continue provisionally to regard it as occurring at the close of the Stephanian, or possibly (as would better suit many of the facts) as late as the middle Permian. The totally unaffected aspect of the topmost Stephanian flora near Mukden in Manchuria and in Italy, as well as of the somewhat earlier Stephanian flora in South Africa, would, if evidence of other kinds to the contrary were absent, tend somewhat strongly to prejudice in favor of the later date. The moderate temperature of the fairly equable "Permo-Carboniferous" climate in general may explain why the shock of the climatic episode was not more severely and for a longer time felt by the cosmopolitan Permian flora of western Europe and America.

PALEOGEOGRAPHIC MAPS OF NORTH AMERICA[1]

BAILEY WILLIS
U. S. Geological Survey

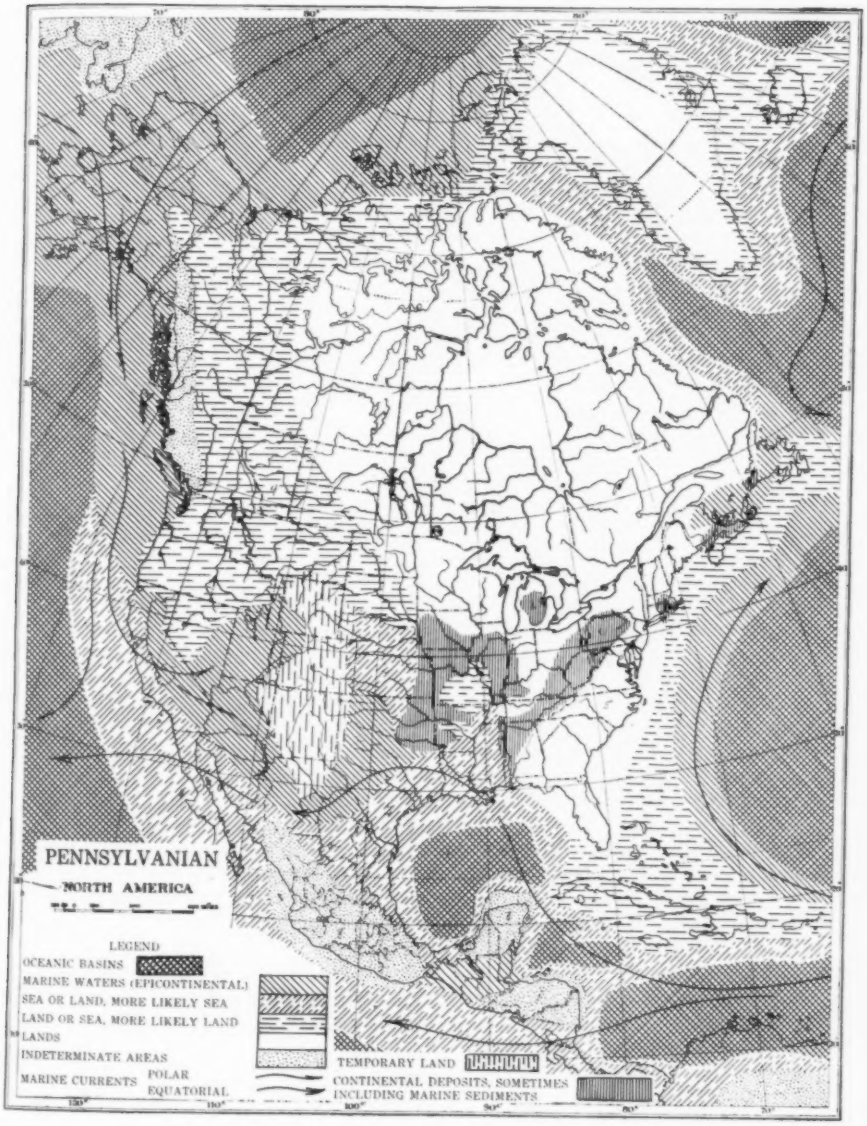
7. PENNSYLVANIAN NORTH AMERICA

The passage from Mississippian to Pennsylvanian was characterized by that emergence of lands, which is indicated on the map by the districts assigned to continental deposits and temporary lands. In the eastern United States the tendency toward emergence was progressive though interrupted. In the central west the emergence was but temporary and the transient land area was submerged under the Pennsylvanian sea. In contrast with the Mississippian, the Pennsylvanian continent probably extended far to the west—north of the fortieth parallel. As is shown by White there was land connection with England and Europe, probably around the North Atlantic.

The southeastern portion of the continent appears to have been embraced by branches of the equatorial Atlantic current. The northwestern part was washed by currents from the Arctic and north Pacific. The period was one during which climatic differences developed, and the situation of North America favored that development. The accumulation of coal in the southeastern portion in contrast to red sediments in the southwestern part may thus be explained as an effect of climate, in the one district favorable, in the other unfavorable to vegetation. Red beds are to some extent interbedded with coal measures, as glacial deposits of the Pleistocene are with interglacial, and it is probable that the relations may be interpreted as evidence of climatic fluctuations.[2]

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *Acknowledgments.*—The maps of Mississippian and Pennsylvanian North America were prepared in conference with Dr. G. H. Girty. As should have been stated in the appropriate connection, the maps of Devonian and Silurian geographies have been improved by data furnished by Dr. E. M. Kindle. The three earlier maps, particularly those of Cambrian conditions, are based on the work of Dr. C. D. Walcott, and have been adjusted to the results of his investigations. I am indebted to each of these scientists and also to many other fellow-geologists, members of the U. S. Survey and others, for suggestions courteously made. They are not responsible, however, for the drafts of the maps.—BAILEY WILLIS.


PENNSYLVANIAN
NORTH AMERICA
LEGEND
OCEANIC BASINS
MARINE WATERS (EPICONTINENTAL)
SEA OR LAND, MORE LIKELY SEA
LAND OR SEA, MORE LIKELY LAND
LANDS
INDETERMINATE AREAS
MARINE CURRENTS
POLAR
EQUATORIAL
TEMPORARY LAND
CONTINENTAL DEPOSITS, SOMETIMES INCLUDING MARINE SEDIMENTS

THE CONVEXITY OF HILLTOPS[1]

G. K. GILBERT

In a maturely developed topography, hilltops composed of unconsolidated materials are upwardly convex in profile. Their forms are thus contrasted with the longitudinal profiles of stream beds, which in mature development are concave upward. An explanation of the river profile offered by the writer more than thirty years ago[2] seems to have been generally accepted. Its fundamental principles are (1) that the transporting power of a stream per unit of volume increases with the volume, (2) that transporting power increases with the slope, and (3) that a stream automatically adjusts slope to volume in such way as to equalize its work of transportation in different parts.

In 1892, Davis proposed an explanation of the convexity of hilltops, ascribing it to creep.[3] His article occupied less than a page of *Science*, and may not have attracted the attention it merited. At any rate Fenneman, in a recent discussion of the same subject, makes no mention either of Davis or of creep; and it occurs to me that a restatement of Davis' explanation may be timely.

Fenneman ascribes the convex profile to running water, making a distinction between the behavior of water near hilltops and lower down. As I find it difficult to do justice to his analysis in an abstract, I refrain from a comparison of his hypothesis with that of Davis, but refer the reader, instead, to his article which is in the *Journal of Geology* for November-December, 1908.[4]

The subjoined presentation of the creep hypothesis, while essentially equivalent to Davis', is independent in respect to various details.

A layer of unconsolidated material resting on a gentle slope holds its position (1) because the particles are arranged so as to support one

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *Geology of the Henry Mountains*, p. 116.

[3] W. M. Davis, "The Convex Profile of Bad-Land Divides," *Science*, XX, 245.

[4] N. M. Fenneman, "Some Features of Erosion by Unconcentrated Wash," *Journal of Geology*, XVI, 746–54.

another, and (2) because one particle cannot slide on another without developing friction. Spherical frictionless particles would flow on the faintest of slopes, and subangular frictionless particles would flow on a moderate slope. Whatever diminishes friction promotes flow. Whatever disturbs the arrangement of particles, permitting any motion among them, also promotes flow, because gravity is a factor in the rearrangement and its tendency is down the slope. Violent agitation by an earthquake suspends for the time the structural arrangement, surcharge by water greatly reduces friction, and each of these may cause flow, the flow phenomena being of the land-slide type.

In creep the chief disturbing agencies are expansion and contraction, and these are caused by freezing and thawing, heating and cooling, wetting and drying. If expansion were equal in all directions, and extended indefinitely downward, the arrangement of the particles —or the structure of the formation—would not be affected; but dilatation is resisted in all directions except outward, and expansion in a single direction modifies the structure. The structure is again modified during the ensuing contraction, and during both changes gravity enters as a constant factor tending downhill.

Prominent among other disturbing agencies are plant roots, which alike in growth and decay occasion soil movements; and roots also act on soils when trees are swayed by the wind. Animals promote creep in a more direct way, for as they walk either up or down a slope their feet push harder downhill than uphill.

Consider now the effect of creep on the law of slope. As we are speaking of mature topography only, we may assume the rate of degradation to be the same on all parts of the slope, so that the two lines in the diagrammatic section, Fig. 1, represent the surface of the ground at two epochs. In the interval between the epochs, there has been no transportation at the summit, *D*; but a volume of material equivalent to the prism enclosed by the lines between *D* and *A* has been carried past *A;* and a volume equivalent to the prism between

FIG. 1.—Diagrammatic section of a hill-top, indicating the zone of creep, and the position of the surface at two epochs.

D and *B* has been carried past *B*. The quantity passing each point of the slope has been proportional to the distance of the point from the summit. If the depth of the creeping layer has been uniform, the mean velocity of creep has been proportional to the distance from the summit. On the other hand the impelling force, gravity, depends for its effectiveness on slope, being able to cause more rapid flow where the slope is steeper. Therefore, on a mature or adjusted profile, the

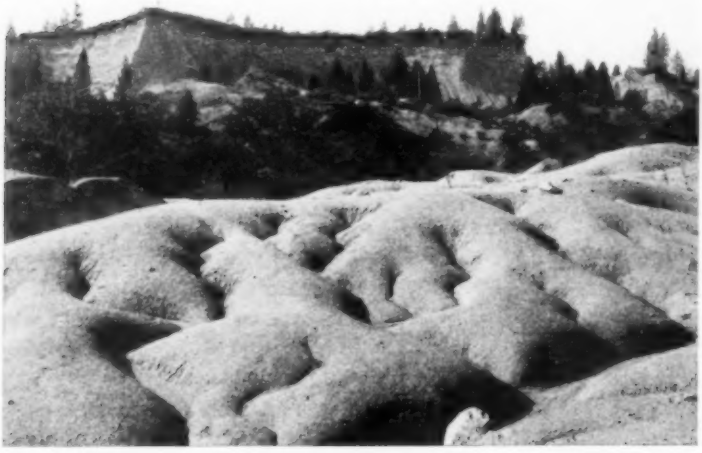


FIG. 2.—Miniature hills, illustrating the convexity of divides and interstream ridges.

slope is everywhere just sufficient to produce the proper velocity. It is greatest where the velocity is greatest, and therefore increases progressively with distance from the summit. In other words the normal product of degradation by creep is a profile convex outward.

If soil creep and carriage by water are the only important processes of transportation operative in a region of maturely sculptured hills, the above analysis seems adequate. On the upper slopes, where water currents are weak, soil creep dominates and the profiles are convex. On lower slopes water flow dominates and profiles are con-

cave. Other factors may be mentioned, but it is probable that they acquire prominence only in special cases.

One of the mentionable factors is wind, which is no respecter of slopes, working as readily uphill as down. Another is rain beat. The two have this in common: that for each locality they have a dominant direction, so that any direct influence they may have on topographic expression tends toward asymmetry.

FIG. 3.—Miniature hills, illustrating the convexity of divides.

There is an indirect effect of rain beat due to its combination with water flow and this follows the direction of water flow. When raindrops beat heavily on the upper slopes there is usually also a diffused flow of water. Particles disturbed by the drops are momentarily suspended by the flowing water and drifted down the slope. Near the summit such transportation is favored by the shallowness of the water sheet but restricted by the slowness of the current. Lower down it is favored by more rapid current but restricted by depth of water, which lessens the effect of impact. Whether the ordinary result is greater transportation near the divides, tending to produce a convex profile,

or greater transportation on lower slopes, tending to produce a concave profile, is not easy to see.

As wind and rain beat are effective only on bare surfaces and surfaces imperfectly clothed by vegetation, while convex hilltops are found alike in forested regions, prairies and deserts, it is evident that their work is not of prime importance in this connection. Soil creep is omnipresent and appears to be competent.

FIG. 4.—Miniature hills, illustrating the convexity of divides.

The development of gullies on convex slopes when vegetal protection is removed, does not import a transformation to concave slopes and acute water partings, but merely a change in what Fenneman aptly calls the texture of the topography—a reduction of the scale of the drainage pattern and hill pattern. The removal of vegetation gives water flow greater velocity, thereby enlarging the domain of stream sculpture, with associated concave profiles, and reducing the domain of creep and convexity.

Figs. 2, 3, and 4 show mature hill forms developed in homogeneous material. They occur on the floors of hydraulic gold mines at

Nevada City, California. The washing away of the auriferous gravels laid bare tracts of decomposed granite in which the feldspars are largely changed to kaolin, and for about twenty years these have been exposed to the elements. There can be little question that here the convexities are due to creep; and the miniature topography illustrates strikingly the contrast between creep and stream work; but the conditions are not so near to normal as to make the forms fully repre-

FIG. 5.—Erosion and sculpture by the beating of raindrops. The material is regolith, exposed in a road cutting. The rain was driven by a strong wind so as to strike the ground in an obliquely ascending direction, from right to left.

sentative. The kaolin is so cohesive when wet as to tolerate slopes far above the "angle of repose," and this leads to an exaggerated expression of the convex profile, shown especially in Fig. 2; and in the other examples there is reason to believe that the positions of gullies were largely determined by shrinkage cracks.

Fig. 5 illustrates the power of raindrop impact to attack unprotected surfaces of waste. In ordinary examples of rain sculpture the

lesson is conveyed by the presence of pillars of earth each capped by a pebble or other protective particle, but it is not easy to determine whether the work of sculpture consumed little or much time. In this particular case the raindrops were driven by so violent a wind as to be swept *up* a slope. The wind in question blew for but a fraction of an hour, but in that brief time the rain beat developed on the earthbank (of regolith) a complete system of furrows and ridges parallel to the direction of the wind.

GEOLOGICAL SECTION OF NEW JERSEY[1]

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PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of New Jersey comprise certain white crystalline limestones with closely associated quartzites and conglomerates and a great complex of granitoid gneisses, pegmatites, and magnetites which, because of their resistance to erosion, underlie the Highlands of the state.

Franklin limestone.—The Franklin limestone in its more common phases is a white, highly crystalline, coarsely granular limestone or marble, ranging in composition from a nearly pure carbonate of lime to a dolomite. Some of it is rather siliceous and in a few places thin beds of sandstone have been noted. At Franklin Furnace and Sterling Hill it contains large beds of zinc ore and magnetite veins are also present in a few places. Graphite is widely disseminated in the limestone, and with mica, pyroxene, and chondrodite frequently gives the rock a gneissic structure.

The Franklin limestone is unconformably overlain by basal members of the Cambrian system. It contains intercalated masses of gneiss, and is injected by numerous bodies of pegmatite, neither of which rocks are associated with the Cambrian formation. On the other hand, the Hardyston quartzite, the lowest member of the Cambrian, locally contains fragments derived from these pegmatites, and even fragments of the coarse-grained limestone itself. That the Franklin limestone was metamorphosed to its present condition long before the deposition of the lowermost Cambrian sediments has been abundantly demonstrated.

The gneisses.—The gneisses appear in many varieties and of different sorts so intricately mingled that detailed representation of

[1] In the preparation of this paper, I have drawn freely from the published reports of my associates on the Geological Survey of New Jersey and of those workers on the U. S. Geological Survey who have dealt with the problems of this area. To Dr. A. C. Spencer, in particular, am I indebted for data on the pre-Cambrian rocks.

their distribution on geologic maps is quite impracticable. The most noteworthy differences of appearance presented by them are those of color, and inasmuch as color-distinctions have been found to correspond broadly with fairly definite lithologic differences, they may be used as a guide in classifying the gneisses for the purposes of description and mapping.

All the dark gneisses which owe their color to the hornblende, pyroxene, or biotite which they contain have been grouped together under the name Pochuck gneiss. The second group, the members of which show brown-gray, bronzy, pink, and ocherous tones, is called the Byram gneiss. Here are included a great variety of granitoid or granite-like rocks related to one another and distinguished from the other gneisses by the presence of potash feldspar as an essential ingredient. A third group, the Losee gneiss, includes light-colored granitoid rocks, many of them nearly white, which contain lime-soda feldspar as an essential and characteristic mineral component.

These varieties of gneiss are seldom found in large masses free from intermixture with other sorts, but the different facies or varieties occur in tabular masses which are interlayered both on a large and on a small scale.

These gneisses, with few exceptions, correspond accurately in their mineralogical and chemical composition with common types of coarse-grained igneous rocks like the granites and diorites. The light-colored granitoid rocks included under the names of Losee gneiss and Byram gneiss are present in the largest amounts. There can be little doubt that they solidified in part out of invading silicate solutions or molten magmas. Evidence of crushing in the minerals of these gneisses is almost entirely wanting, and appearances strongly favor the belief that the gneissic foliation is original in these intrusive rocks of the pre-Cambrian complex.

The dark Pochuck gneisses have the composition of igneous diorites or gabbros, but whether they have been derived from igneous or sedimentary originals, or, as is believed, in part from both, their present characteristics have in most places been acquired by metamorphism, involving secondary crystallization. Foliation is everywhere present in these dark rocks, and parallel to this structure they are injected in all proportions by sheets of light-colored material

similar in composition to phases of the Losee gneiss. They are also interlayered with both the Losee and Byram gneisses on a broad scale, and the Franklin limestones are similarly interlayered with the granitoid gneisses, so that these two sets of rocks—the dark Pochuck gneisses and the Franklin limestones—together seem to constitute a matrix holding the intrusive granitoid rocks in the form of relatively thin but extended plates.

Though the Pochuck gneiss and the Franklin limestone are both regarded as older than the granitoid gneisses, the original relations between them are not determinable.

Apparently the dark rocks were already foliated before they were invaded, because the interlayering of the granitoid materials is so regular that the presence of some structural control would seem to have been a necessity, but during this deformation the early texture of the rock was broken down, important addition or subtraction of elements may have occurred, and a later crystallization ensued contemporaneous with the crystallization of the injected material. The forces causing flowage probably continued to operate after crystallization had begun, and practically until it was complete, so that the injection of the granitoid material, the pressing out and kneading of the masses of the matrix, and the development of textural foliation in both were phenomena connected in origin with a single cause.

The Franklin limestone locally retains traces of original stratification, showing its sedimentary origin, but the lamination observed within masses of this rock is regarded mainly as a sort of flow structure developed through the crystallization of the limestone masses while they were being molded under the action of deforming stresses and at the same time traversed by mineral-charged waters derived from the invading Losee and Byram magmas. The facts are believed to warrant the conclusion that the white limestones and the various gneisses with which they are associated, together with the ore-deposits which they inclose, crystallized in their present state and received their present forms as geologic masses during a single period of regional deformation.

PALEOZOIC FORMATIONS

The Paleozoic rocks comprise representatives of the Cambrian, Ordovician, Silurian, and Devonian systems. They outcrop (*a*) in a

few small areas southeast of the Highlands between the pre-Cambrian crystallines and the Mesozoic strata, (*b*) in narrow valleys within the Highlands, (*c*) in a board belt northwest of the Highlands, the latter area comprising the northern extension of the great Appalachian valley and the mountain west of it.

CAMBRIAN SYSTEM

Hardyston quartzite.—The Hardyston quartzite is the lowest formation of the Cambrian system, and is probably to be correlated with the Poughquag quartzite of Dutchess County, N. Y., and the Chickies quartzite of Pennsylvania. It is unconformable on the pre-Cambrian complex and is the oldest fossiliferous rock in New Jersey. It varies considerably in composition and thickness. Typically it is a quartzite, at many places conglomeratic and containing pebbles of quartz, feldspar, granite, gneiss, and slate. Locally the formation is a calcareous sandstone. It is usually but not invariably feldspathic. In some localities its arkose character is so marked that it is not readily distinguishable from a coarse granite. Beds of slate occur in its upper portion.

Its thickness ranges from a few feet to 200 or more, and it passes into the overlying sandstone through slaty or shaly layers, several of which are in places interbedded with limestone layers, so that its upper limits are indefinite. Since it contains a species of Olenellus, it is regarded as of Georgian (Lower Cambrian) age.

Kittatinny limestone.—The Hardyston quartzite grades upward into the thick magnesian Kittatinny limestone of the Kittatinny Valley. Above, it is limited by an unconformity at the base of the Jacksonburg (Trenton) limestone. The presence of thin shales and scattered seams of sandstone in the great mass of limestone shows an influx of land sediments at recurrent intervals during its formation.

The known fauna of the Kittatinny limestone is not extensive and is found at but few localities, but it suffices to establish the Cambrian age of the greater part of the formation. No Middle Cambrian fossils have been found, but as the Olenellus fauna of the Hardyston quartzite is considered to be of Lower Cambrian age, and as no evidence of a break in sedimentation has been observed, a Middle Cambrian fauna would naturally be expected between the Olenellus

fauna below and the Dikelocephalus fauna above. In one locality a fauna of Ordovician (Beekmantown) age has been found in beds near the top of the Kittatinny limestone. This formation, therefore, where complete, represents a period extending from the middle or upper part of the Lower Cambrian to the lower part of the Ordovician, inclusive.

ORDOVICIAN SYSTEM

In northern New Jersey, as elsewhere in the great Appalachian valley, there is no sharp line of demarkation between the rocks of the Cambrian and those of the Ordovician system. The base of the Ordovician lies somewhere below the top of the Kittatinny limestone, as stated above, but the exact position of this division line cannot readily be determined.

Jacksonburg limestone.—Above the Kittatinny limestone, and separated from it by a break in sedimentation indicated by a calcareous basal conglomerate, is a dark-blue or black fossiliferous limestone, correlated with the Lowville, Black River, and lower Trenton limestone of the New York section and hitherto classed as "Trenton," some layers of which contain as much as 95 per cent. or more of calcium carbonate. Calcareous shales occur interbedded with these limestones and above them to the top of the formation. The sequence of conglomerate, limestone, and shale is a variable one, but, so far as observed, the transition to the overlying formation is always through a series of calcareous shales which become less and less limy.

The thickness of the Jacksonburg formation varies from 135 to 300 feet or more. It contains an abundant fauna, ninety-eight forms having been described by Weller. At the type locality the lower strata for a thickness of fifty-eight feet carry a Lowville–Black River fauna, and the higher beds have a lower Trenton fauna.

Martinsburg shale.—The Jacksonburg limestone passes upward through the calcareous shales mentioned above into a great thickness of shale, slate, and sandstone, which has heretofore been known as the "Hudson River slate," but which is now correlated with the Martinsburg shale of West Virginia and takes that name.

The formation ranges from the finest-grained shale and slate to fine sandstone. The former beds on the whole are black and more abundant in the lower part, whereas the sandstone beds are dark

bluish-gray, many of them calcareous, and occur more commonly higher in the formation. The fine-grained rocks exceed the gritty beds.

Slaty cleavage is the predominant structure of the fine-grained beds, and the true bedding planes are in many places difficult to determine. At some horizons the planes of cleavage are so straight and parallel and the rock so even textured that commercial slates have been obtained in considerable quantities. The whole formation is so crumpled and cleaved that no accurate estimate of its thickness can be made, but it is probably at least 3,000 feet, and it may be more.

Four species of graptolites characteristic of the Normanskill fauna of New York have been found in the lower portion of the Martinsburg shale, so that the beds in which they occur are equivalent in age to the middle portion of the typical Trenton limestone of central New York. A few miles north of the New Jersey state line, Schizocrania and graptolites characteristic of the Utica shale of the Mohawk Valley have been found in beds close to the overlying Shawangunk conglomerate.

SILURIAN SYSTEM

Contrary to long-prevalent, and apparently well-established belief, the lower and middle portions of the Silurian system are not represented in New Jersey. Their absence in this and adjoining regions is indicative of somewhat widespread earth movements unaccompanied in this region by folding, which closed the period of deposition indicated by the Martinsburg sediments or possible overlying beds afterwards removed by erosion and raised the region above the zone of sedimentation. When deposition began again late in Silurian time, beds of coarse conglomerate were laid down, followed by sandstones, shales, and limestones, the earlier sediments being those of a low-grade delta in an arm of the Appalachian gulf.[1] These conditions of deposition prevailed with but slight changes of elevation into Devonian time.

Shawangunk conglomerate.—The Shawangunk conglomerate (the Oneida conglomerate of many previous publications) is chiefly a

[1] Clarke, *N. Y. State Museum Bulletin 107*, p. 303.

coarse quartzite and conglomerate composed of small white-quartz pebbles imbedded in a siliceous matrix. Its color is generally steel blue, but some beds have a yellowish tinge, and reddish layers occur near the top. Layers of black shale a few inches in thickness are locally intercalated between thick beds of conglomerate and grit. Between this formation and the Martinsburg shale there is a gap representing the upper part of the Ordovician and all of the Silurian below the Salina of the full New York section, but there is no marked divergence of dip and strike where the two formations outcrop in proximity, and the actual contact is nowhere exposed in New Jersey. The beds overlying the Shawangunk conglomerate are red sandstone and shale, and the transition from the Shawangunk is made through a series of alternating red sandstone and gray conglomerate, so that the upper limit of the Shawangunk is not sharply defined. Its thickness is probably from 1,500 to 1,600 feet.

So far as known, the formation is barren of fossils in New Jersey, but at Otisville, N. Y., a euryterid fauna has been found in the black shale intercalated with the conglomerate. In the Otisville section this fauna, which elsewhere appears only and briefly at the base of the Salina, repeats itself many times through a thickness of 650 feet.[1] The Shawangunk conglomerate is followed by 2,500 feet or more of shales and limestones also referable to the Salina; hence for this region it represents only the lower portion of that group.

High Falls formation.—The red sandstone and shale which immediately overlie the Shawangunk conglomerate have until recently been regarded as the equivalent of the Medina sandstone of New York and have been so called, but, for the reasons just cited, it is evident that they are much younger than Medina and that they must be included in the Salina group. Moreover, they lie some distance below a limestone which is correlated with the Cobleskill of the New York section. The name High Falls has been applied to the red shales that overlie the Shawangunk conglomerate in Ulster County, N. Y., and has been adopted for New Jersey in place of Medina, which is not applicable.

The lower beds consist of a hard red quartzitic sandstone, intercalated with some green or gray sandstones and softer red shales

[1] Clarke, *op. cit.*, p. 303.

which become more abundant in the upper part of the formation. The formation has an estimated thickness of 2,300 feet at Delaware Water Gap. It is not known to contain fossils, but its age is fixed by its stratigraphic position.

Green Pond conglomerate.—The formation known as the Green Pond conglomerate occurs in an isolated belt of Paleozoic rocks which extends through the middle of the pre-Cambrian Highlands of New Jersey. In constitution it is similar to the Shawangunk conglomerate, with which it is correlated, but, inasmuch as it is still an open question whether the Paleozoic strata of the Green Pond Mountain region were once continuous with the great mass of Paleozoic sediments which lie some distance to the northwest, or whether the Green Pond region represents a separate basin shut off on the northwest from the large Paleozoic sea although communicating with it to the northeast, it has seemed best to retain for the present at least both Shawangunk and Green Pond as names for these conglomerates in their respective fields.

Longwood shale.—Immediately above the Green Pond conglomerate, and conformable with it, is a soft, red shale, in which an irregular cleavage is usually so highly developed that the bedding planes can be determined only with difficulty. The formation is not known to contain fossils, but, as it rests directly upon the Green Pond conglomerate and is followed by a limestone carrying a Salina fauna, it is probably of Salina age. Its stratigraphic position is, in general, the same as that of the High Falls formation, but the two may not be exactly synchronous.

FORMATIONS ABOVE THE HIGH FALLS AND LONGWOOD SHALES

The higher Silurian and the Devonian formations of New Jersey occur either in Wallpack Ridge, which lies along the northwestern border of the state in the upper Delaware Valley, or in the narrow belt of Paleozoic rocks in the midst of the Highlands in the Green Pond Mountain region. In Wallpack Ridge they aggregate 1,300 feet or more, while in Green Pond Mountain region they have a thickness of about 4,000 feet, of which all but 250 feet are referable to beds higher than any of those along Wallpack Ridge.

Poxino Island shale.—The top of the High Falls shale in New Jersey is everywhere buried by glacial drift which also conceals the beds immediately superjacent. The next recognizable formation is the Poxino Island shale, a buff or greenish calcareous shale in thin layers and non-fossiliferous so far as known. Its outcrops along the base of Wallpack Ridge in the upper Delaware Valley are few, small, and widely separated, and very little is known regarding it. In the adjoining portion of Pennsylvania it is reported to be 200 feet in thickness, and to rest on a thin limestone formation which in turn rests on the High Falls shale. It is not known to occur in the Green Pond Mountain region.

Bossardville limestone.—A fine-grained, compact, bluish-gray, banded limestone, known as the Bossardville limestone, lies conformably upon the Poxino Island shale in Wallpack Ridge. It increases in thickness from 12 feet at the New York state line to about 100 feet where it crosses the Delaware River into Pennsylvania. Owing to its marked banding it was for many years known as the "Ribbon" limestone and was correlated by Cook and later geologists with the Ribbon or Manlius limestone at Rondout, N. Y. In reality it lies below the Manlius limestone. It is only sparingly fossiliferous but is immediately succeeded by a series of beds containing a well-defined Salina fauna. It has not been recognized in the Green Pond Mountain belt, but this may be from lack of exposures.

Decker Ferry formation.—Under the name *Decker Ferry formation* a series of beds has been described, which are chiefly limestones at the north and calcareous sandstones at the southwest. Their thickness is 52 feet at the Nearpass quarry near Tri-States where the section can be accurately measured. Thin bands of more or less fissile green shale separate the limestone beds. A thin band of red, crystalline, highly fossiliferous limestone occurs about the middle of the series and is a striking feature. The lower 42 feet of these beds as exposed at the type locality are correlated[1] with the Wilbur limestone (the so-called "Niagara" or "Coralline" limestone of Hall and other authors) and the "black cement" beds, i. e., the Salina "water lime" of the Rondout section of New York. These form the top of the Salina group, the base of which in New Jersey is the base of the

[1] Hartnagle, *New York State Museum Bulletin 69*, p. 1152.

Shawangunk conglomerate. The upper ten feet of the Decker Ferry series contain fossils, particularly in the lower half, which render necessary their correlation with the Cobleskill limestone of eastern New York.

In the Green Pond Mountain region isolated outcrops of impure limestone occur a short distance above the Longwood shale, which contain a fauna that correlates them with the lower beds of the Decker Ferry formation, i. e., to the part referable to the Salina group.

Rondout limestone.—Along the upper Delaware the beds immediately above the Decker Ferry limestone and referred to the Rondout consist of more or less earthy shales and limestones the thickness of which is 39 feet. They are usually only sparingly fossiliferous, although in some beds the crustacean Leperditia is abundant. A typically marine fauna, with an abundance of brachiopods, trilobites, etc., is conspicuously absent in these beds. In general lithologic features this formation resembles the Rondout as developed in New York state, but the cement beds which are so characteristic of this formation farther north are not present here.

Manlius limestone.—The Rondout is succeeded conformably by a somewhat thin-bedded, knotty, dark-blue or almost black limestone, 34 to 35 feet thick where best exposed. It is the bed which constitutes the quarry stone of the Wallpack Ridge and its outcrop is marked by a line of quarries and lime kilns. It is referred to the Manlius or "Tentaculite" limestone of the New York series, although well-preserved specimens of the characteristic fossil *Tentaculites gyracanthus* Eaton are rare. In the lower beds there is evidence of environmental conditions similar to those of the Rondout. In the middle portion, Leperditia is still abundant, but is associated with a prolific brachiopod fauna, suggestive of the recurrence of more typical marine conditions. In the upper beds Leperditia has entirely disappeared, and the fauna is normally marine. No beds referable to the Rondout or Manlius have been detected in the Green Pond Mountain region, although their attenuated representatives may occur.

THE DEVONIAN

The Devonian formations of the upper Delaware Valley are of marine origin and are chiefly fossiliferous calcareous shales and

limestones having a thickness of about 1,000 feet. Those of the Green Pond Mountain region are chiefly arenaceous shales, sandstones, and conglomerates, carrying comparatively few fossils, and aggregating over 4,000 feet in thickness.

The Helderbergian or lowermost Devonian faunas in New Jersey are essentially the same as those in New York, and the same faunal zones are recognized. The first formation carrying these faunas is the Coeymans limestone.

Coeymans limestone.—In the Nearpass section, the Coeymans limestone has an estimated thickness of forty feet, though only the lower beds are exposed. It rests conformably upon the Manlius limestone from which it differs lithologically in its coarser and more crystalline texture and lighter color. Frequently more or less chert is mingled with the limestone. The Coeymans fauna is far more prolific than that of the Manlius and differs markedly in composition, the most characteristic species being *Gypidula galeata*. A coral bed carrying more or less completely silicified masses of *Favosites helderbergiae*, and a concentrically laminated stromatoporoid occurs in the base of the formation.

Stormville sandstone.—In the southern half of the Wallpack Ridge in New Jersey, a thin sandy layer occurs at the top of the Coeymans limestone. It is in general an inconspicuous formation owing to its thinness and heavy deposits of glacial drift. It becomes more conspicuous toward the south and according to White[1] it gradually replaces the overlying calcareous and shaly strata until it occupies the entire interval between the Coeymans limestone and the Oriskany sandstone. It has not been recognized in the Nearpass section near Tri-States nor at any point north of Hainesville, N. J.

New Scotland beds.—The New Scotland beds which overlie the Coeymans limestone in the Nearpass section consist of about 20 feet of a very hard cherty limestone followed by a series of calcareous shales, having an estimated thickness of 140 feet. Nowhere in the state is there exposed a continuous section of these beds as is the case with several of the lower formations. The fauna is a prolific one, and is especially characterized by the abundant representation of the genus Spirifer. Its differences from the Coeymans fauna are of

[1] Second Geol. Surv. Penn., *Rep. G 6*, pp. 132, 133.

such an essential character as to indicate a separate immigration from the exterior into this region.[1] As indicated above, south of Hainsville, a thin sandy bed intervenes between the Coeymans limestone and the New Scotland beds and gradually replaces the latter. At Flatbrookville, where these strata cross the Delaware into Pennsylvania, the lower cherty limestone member of the New Scotland beds has disappeared, and the Stormville sandstone contains a fauna characterized by *Spirifer macropleurus*.

Becraft limestone.—A hard, gray, cherty limestone overlies the shaly layers of the New Scotland beds, forming a resistant layer which outcrops frequently along Wallpack Ridge. Its entire thickness has never been observed, but it is estimated to be about twenty feet. Its fauna is closely allied to that of the New Scotland beds, a few new forms appearing and a few old ones disappearing. There is also some difference in the proportionate number of individuals of some species, notably of *Leptaena rhomboidalis* which becomes especially abundant. The bed is correlated with the Becraft limestone of New York.

Kingston or Port Ewen beds.—A series of strata, nowhere exposed, occupies the interval between the Becraft limestone and the base of the Oriskany. They are probably shaly beds which easily disintegrate and thus become covered with débris. Their thickness is roughly estimated as eighty feet. The only basis for their correlation is their position which corresponds to that of the Port Ewen (Kingston) beds of New York. In Pennsylvania, the same beds have been called the Stormville shales by White.[2]

Oriskany formation.—A series of strata, aggregating about 170 feet in thickness, succeed the Port Ewen beds and are referred to the Oriskany. They are for the most part siliceous limestones, but the summit of the formation along the southern half of the Wallpack Ridge becomes a sandstone. The arenaceous facies is said to become more marked to the southwest in Pennsylvania and to embrace lower and lower beds until all the strata to the top of the Coeymans limestone are sandstones. The fauna of the Oriskany beds in New Jersey comprises three well-defined faunal zones, the lowest character-

[1] Weller, N. J. Geol. Survey, *Paleontology*, Vol. III, p. 90.

[2] Second Geol. Surv. Penn., *Rep. G 6*, p. 131.

ized by *Dalmanites dentatus*, the second by *Orbiculoidea jervensis*, and the third by the great abundance of *Spirifer murchisoni*.

In the Nearpass section the beds bearing the *Dalmanites dentatus* fauna are about 30 feet thick and form the crest of a high ridge which is the southern extension of the "trilobite ridge"[1] east of Tri-States. There is a mingling of Helderbergian and Oriskanian forms in this fauna, and there has been some difference of opinion as to whether these beds should be placed in the Port Ewen or Oriskany, but recent workers[2] unite in referring them to the Oriskany.

Esopus grit.—The Esopus grit which overlies the sandstones and siliceous limestones of the Oriskany forms the crest of Wallpack Ridge for the greater part of its extent in the state. It is a nearly black gritty rock with well-developed cleavage, which obscures the bedding planes. The fucoid "cauda galli" markings can frequently be recognized on the bedding planes when the latter can be distinguished. Apart from these markings fossils are very rare. The average thickness of the formation in New Jersey is estimated to be 375 feet.

Onondaga limestone.—The Onondaga limestone overlies the Esopus grit along the northwestern slope of Wallpack Ridge. Toward its base the formation is somewhat shaly and there is apparently a rather gradual transition from the grit to the limestone. The latter is hard, cherty, and regularly bedded in layers ranging from three inches to one foot in thickness. The beds are assigned to the Onondaga on the basis of their position and lithology rather than faunal evidence, since the recognizable forms are not sufficiently characteristic for close correlation.

Marcellus shale.—Fissile black shale, referable to the Marcellus, has been reported to occur in New Jersey along the bed of the Delaware River a few miles below Port Jervis, but in recent years the exposures have apparently been buried by silting-up of the channel. This is the highest of the Devonian beds exposed in the state along the Delaware River, but in the Green Pond Mountain area still younger beds occur.

[1] Shimer, *New York State Museum Bulletin 80*, pp. 175 f.

[2] Weller, Geol. Surv. of N. J., *Paleontology*, Vol. III, p. 96. Shimer, *op. cit.*, p. 184.

DEVONIAN FORMATIONS IN THE GREEN POND MOUNTAIN AREA

Kanouse sandstone.—The Kanouse sandstone, the lowest Devonian formation of the Green Pond Mountain region, is a thick-bedded, fine-grained conglomerate below, and a greenish sandstone above, having a thickness of about 215 feet. Although fossils are not rare, yet as a rule they are obscure, and many of them are so greatly distorted that their identification is impossible. So far as recognized they indicate an Onondaga fauna, and these beds may be interpreted as the shoreward correlatives of the Onondaga limestone. It is the formation which in the New Jersey Geological Survey reports has been called the Newfoundland grit.

Its outcrops form a narrow belt parallel to the Decker Ferry limestone, but separated from it by a narrow interval. In the upper Delaware Valley, as noted above, there are seven formations aggregating nearly 900 feet in thickness between the Decker Ferry and the Onondaga. In the Green Pond Mountain region none of these has been recognized and, if present at all, it can be only in very attenuated form.

Pequanac shale.—The Kanouse sandstone apparently grades upward into a black and dark-gray, thick-bedded, slaty shale (the "Monroe" shale of Darton and others). Cleavage is usually strongly developed so that the bedding planes are not always readily discernible. The thickness is estimated at 1,000 feet. This formation is probably conformable upon the Kanouse sandstone, but the contact has nowhere been observed. It contains a somewhat meager fauna among which, however, is the characteristic Hamilton species, *Tropidoleptus carinatus*, so that its reference to this period is beyond question.

Bellvale sandstone.—The Bellvale sandstone is scarcely more than a continuation of the Pequanac shale, but the beds are coarser and more sandy. The average thickness is estimated at 1,800 feet. The few fossils found are all Hamilton species.

Skunnemunk conglomerate.—The Bellvale sandstones grade upward into a coarse, purple-red, massive conglomerate, the white-quartz pebbles of which are sometimes 6 or 7 inches in diameter Beds of red, quartzitic sandstone alternate more or less frequently with the conglomerate and there are many gradations between the two. It forms the great mass of Bearfort Mountain in New Jersey

and of Bellvale and Skunnemunk mountains in New York. It is the youngest Devonian formation in New Jersey and rests upon beds known by their fossils to be of Hamilton age. Whether it is the exact equivalent of the Chemung-Catskill cannot be determined.

STRUCTURE OF THE PALEOZOIC FORMATIONS

The Paleozoic rocks have the northeast-southwest structure lines characteristic of all parts of the Appalachian province, due primarily to a system of folds and faults whose trend is in that direction. The folds are rarely symmetrical, southeastward dips being usually less steep than northwest dips, so that the axial planes are inclined to the southeast. The folding took place during the Appalachian revolution and is most marked in the beds farthest southeast and diminishes rapidly to the northwest. Some overthrust faulting occurred during the folding, so that now isolated masses of Kittatinny limestone rest upon the Martinsburg shale. The more conspicuous dislocations, however, are due to nearly vertical faults parallel or oblique to the axes of the fold, by which the northwest side has been usually uplifted relatively to the southeastern. These faults are referred to disturbances occurring at the close of the Triassic sedimentation.

TRIASSIC SYSTEM

The Mesozoic era is represented by formations referable both to the Triassic and to the Cretaceous systems. The Triassic rocks occupy a broad belt southeast of the Highlands and extend across the north-central portion of the state from northeast and southwest, their southeastern margin being approximately a line drawn from Trenton to Jersey City. They comprise both sedimentary and igneous rocks, the former chiefly shale, the latter extrusive basalt and intrusive diabase. They rest unconformably upon the early Paleozoics and pre-Cambrian crystallines and along their southeastern margin they are in part overlaid conformably by beds of Cretaceous age. The structure is monoclinal, the strata being inclined at low angles to the northwest, but locally broad, shallow folds have been developed. The beds are cut by many nearly vertical normal faults, the amount of dislocation varying from a few inches to several thousand feet. The rocks are sparingly fossiliferous, footprints of reptiles, a few

species of fish, and a small crustacean being the chief elements of a meager fauna.

Three divisions have been made on lithologic grounds: at the base the *Stockton* beds, comprising arkosic conglomerates and sandstones with some shales; above these the *Lockatong* beds, consisting of black shales, hard, massive, dark argillites, flagstones, and occasional very impure, thin, limestone layers; and at the top a great thickness of very soft argillaceous red shale, the Brunswick beds, which are more typical of the whole series than either of the other groups. Massive conglomerates at various points, chiefly along the northwest border adjoining the Highlands, replace these types at various horizons. Ripple marks, mud cracks, rain-drop impressions, reptile footprints are not uncommon in the finer shales, and cross-bedding, plunge and flow structure, and rapid variations of texture are characteristic of the coarser beds.

These sediments have been regarded as (1) deposits in broad shallow estuaries in which subsidence went on *pari passu* with deposition; (2) lake sediments; (3) sediments in orographic valleys made by rivers of enormous width; and (4) subaërial stream deposits on a piedmont plain fronting a newly uplifted crystalline foreland from which numerous short but vigorous streams derived the sediments which were deposited in coalescing alluvial fans. Occasional downward movements of warping or faulting gave opportunity for local thickening of the deposits along the belts affected. The latter view is perhaps the more likely, although the first still has its adherents.

Four or more periods of eruption at considerable intervals gave rise to three great sheets of basalt each of which is conformable to the beds on which it rests, and each of which was buried by continued sedimentation. The intrusion of a thick sill of diabase obliquely across the strata occurred toward the close of sedimentation. Uplift accompanied by northwestward tilting and normal faulting terminated the deposition of these beds, caused the displaced strata to be beveled off across the upturned edges, revealing the edges of the buried basalt and diabase sheets, and brought up again the crystallines which in adjoining states, and to some extent in New Jersey, skirt the southeast border. The constructional topography due to these orographic movements was largely, if not entirely

obliterated by erosion previous to the deposition of the Cretaceous sediments which overlap the beveled edges of the Triassic beds along their southeastern margin, and which formerly extended much farther northwestward than at present.

THE CRETACEOUS SYSTEM

The Cretaceous strata rest unconformably upon the beveled edges of the Triassic shales along their southeastern margin. They comprise unconsolidated sands and clays, which dip 50 to 25 feet per mile to the southeast, and which have an aggregate thickness of from 500 to 1,000 feet, the greater thickness being formed in the northern portion. The lowermost beds are referred to the upper part of the Lower Cretaceous and are of non-marine origin. The middle and upper portions, however, belong to the Upper Cretaceous and contain an abundant marine fauna.

Raritan formation.—The Raritan formation is extremely variable, consisting chiefly of light-colored sands and clays, some of the latter being highly refractory. There is on the whole a preponderance of clays in the lower and of sands in the upper half of the series. Since it was laid down on an irregular surface its thickness is variable, ranging from 150 to 250 feet at the outcrop, but increasing to the southeastward, as shown by well-borings, to over 500 feet. Northeast of Trenton it rests unconformably upon the beveled Triassic shales, but farther southward upon the ancient crystallines of early Paleozoic or pre-Paleozoic age, and perhaps at undetermined points still farther south on earlier Cretaceous beds. It dips 40 to 50 feet per mile to the southeast, the basal beds having the steeper inclination. The known fauna is very limited, consisting of a few pelecypods, some of which are brackish-water types while two are typically marine, a plesiosaurian bone, and possibly an insect. Its flora embraces a wide range of genera and species, especially of dicotyledons, many of which are closely related to modern forms. It has been regarded by Ward as late Lower Cretaceous and, therefore, approximately equivalent to the Gault of England.

Magothy formation.—The lignitic sands and clays referred to the Magothy formation and regarded as the lowermost of the Upper Cretaceous formations were until recently included in the Raritan.

On the shores of Raritan Bay they attain a thickness of 175 feet but diminish to the southwest and along Delaware River are only 25 or 30 feet. They are slightly glauconitic near the top. The Magothy rests unconformably on the Raritan but the discordance is not great and indicates only a slight epeirogenic movement. A marine fauna of 43 species, possessing close affinities to that of the Ripley beds of the south and to the Senonian of Europe, is found on the shores of Raritan Bay, but farther southwest the deposits are apparently estuarine. The flora is abundant and presents a much more recent aspect than that of the Raritan. It is regarded by paleobotanists as showing Cenomanian affinities.

Merchantville clay.—The Merchantville is a black, glauconitic, micaceous clay, usually greasy in appearance and massive in structure, weathering to an indurated brown earth. Its thickness is about 60 feet. It is conformable to the Magothy formation below and the Woodbury clay above. Its fauna is large and varied and although it contains many forms common to the beds above and below, its most characteristic species are conspicuous for their absence or great rarity in the adjoining strata. The Merchantville clay represents the lower part of the Crosswicks clay of Clark, forms the base of the Clay-marl series of Cook, and is the lowest of the five formations in New Jersey which are correlated with the Matawan formation of Maryland.

Woodbury clay.—The Woodbury is a black, non-glauconitic, jointed clay about 50 feet thick, which weathers to a light chocolate color, and when dry breaks into innumerable blocks, frequently with a conchoidal fracture. Its fauna of 95 marine species is more closely allied to that of the Magothy than to the subjacent Merchantville. It is conformable both with the Merchantville below and the Englishtown sand above. It is the upper part of the Crosswick clay of Clark, and forms part of the Clay-marl series of Cook. It is also one of the formations correlated with the Matawan of Maryland.

Englishtown sand.—The Englishtown is a conspicuous bed of white or yellow quartz sand slightly micaceous and sparingly glauconitic. Locally it contains thin laminae of fine brittle clay. So far as known it contains no fossils. It decreases in thickness from 100 feet near Atlantic Highlands to less than 20 feet in the southern portion of the state. It represents the lower part of the Hazlett sand of

Clark, and forms a part of Cook's Clay-marl series. It was formerly called the Columbus sand and is the equivalent of a part of the Matawan formation.

Marshalltown clay-marl.—The Marshalltown ranges from a black sandy clay to an argillaceous greensand marl. Locally it is abundantly fossiliferous, its characteristic species being in part recurrent forms from the Merchantville, and in part a new element, which recurs again in a higher formation although absent or inconspicuous in the immediately succeeding beds. Its thickness is 30 to 35 feet. It is a portion of the "laminated" sands which formed the upper part of the Clay-marl series of Cook, although in the southwestern portion of the state he referred these beds to the Navesink (Lower) marl. It was included in Clark's Hazlett sands, a subdivision of his Matawan.

The Wenonah and Mount Laurel sands.—Above the Marshalltown clay-marl there is a considerable thickness of sand regarding which there has been some difference of opinion. The terms Wenonah and Mount Laurel have both been applied to them in whole or in part. Lithologically they are not sharply differentiated from each other, although the lower part (Wenonah) is generally a fine micaceous sand and the upper part (Mount Laurel) is coarser and contains considerable greensand. Paleontologically, however, they are quite distinct. The Wenonah fauna is largely recurrent from the Woodbury, with comparatively few prominent species common either to the Marshalltown below or the Mount Laurel and Navesink above. The same elements are prominent again still higher in the Red Bank. The Mount Laurel fauna is identical with that of the Navesink above, and is closely allied to the Marshalltown, but contains a foreign element, chief among which is the cephalopod *Belemnitella americana* and the brachiopod *Terebratella plicata*, so that the indistinct lithological line between the Wenonah and Mount Laurel sands is of considerable paleontological singificance. The combined thickness of these formations is 40 to 80 feet, the Mount Laurel being limited to a very thin bed at Atlantic Highlands (Cook's sand-marl) but increasing much in thickness toward the southwest. The Wenonah sand is the highest bed correlated with the Matawan of Maryland, while the Mount Laurel is the base of the Monmouth.

Navesink marl.—The Navesink marl consists of greensand marl,

mixed with varying amounts of quartz sand and fine earth, the latter of which contains much carbonate of lime in a powdery state. Where purest the marl has a dark-green or bluish-black color. The upper part of the bed contains progressively less greensand and is more clayey. The fauna is large (121 species, Weller), and is allied with that of the Marshalltown and Merchantville beds, while the characteristic forms of the Magothy, Woodbury, and Wenonah are absent. The formation has a maximum thickness of about 40 feet, diminishing southward to 25 feet or less. It corresponds in general to Cook's Lower Marl, although locally beds referred by him to the Lower Marl have proved to be the Marshalltown. It rests conformably upon the beds below and grades upward into the Red Bank sand, or where that is absent into the Hornerstown marl.

Red Bank sand.—The Red Bank sand is for the most part a fairly coarse ferruginous yellow and reddish-brown quartz sand, locally indurated by the infiltration of iron. The lower beds are in many places somewhat clayey. The Red Bank fauna has come chiefly from these clayey layers. In its essential features it is a recurrence of the *Lucina cretacea* fauna of the Magothy, Woodbury, and Wenonah formations, and differs in important respects from the Navesink fauna immediately below. It occurs only in the northern part of the coastal plain where its maximum thickness is 100 feet, but it thins out and disappears midway across the state. It is the Red Sand of Cook and earlier writers but does not include certain sands in the southern portion which were correlated by him with the Red Sand of Monmouth County. With the overlying Tinton bed, it is the uppermost of the beds correlated with the Monmouth formation of Maryland.

Tinton bed.—A lense of green indurated clayey and sandy marl, having a thickness of from 10 to 20 feet, overlies the Red Bank sand in Monmouth County. Its fauna is more closely allied to that of the Navesink than of the Red Bank and is characterized by large numbers of crustacean claws of the genus Callianassa. It is Cook's "indurated green earth," regarded by him and other writers as a part of the Red Sand, but in view of its faunal and lithologic differences it deserves some separate recognition.

Correlation of the Magothy-Tinton beds.—The assemblage of fossils making up the faunas of the beds from the Magothy to the

Tinton inclusive constitute a larger faunal unit, much more sharply separated from the faunas above and below than are any of its constituent faunules from each other. Weller has shown that this larger faunal unit is made up of two or more distinct facies, one of which, the Cucullaea fauna, is characteristic of the more glauconitic beds; namely, the Merchantville, Marshalltown, Navesink, and Tinton, while the other facies characterized by *Lucina cretacea* or its associates occurs in the clays or clayey sands of the Cliffwood, Woodbury, Wenonah, and Red Bank formations. The two facies existed contemporaneously and migrated backward and forward across the present outcrop of these beds in New Jersey as deeper or shallower water conditions prevailed. The larger faunal unit is closely related to the Ripley fauna of Alabama, Mississippi, and Texas. On faunal evidence all the formations from the Magothy to Tinton inclusive are referable to the Senonian of Europe, although on floral evidence the Magothy might be regarded as Cenomanian.

Hornerstown marl.—The Hornerstown marl is a bed of glauconite with clay and sand and not differing materially from the Navesink. Its fauna is meager but is totally different in its essential characteristics from the faunas of all the underlying formations. *Terebratula harlani*, *Cucullaea vulgaris*, and *Gryphaea dissimilaris* (Weller) are characteristic forms. A shell bed at the top of the formation is a conspicuous feature at many localities. The thickness is 30 feet or less. At the north it rests with apparent conformity on the Tinton, where that is absent it lies on the Red Bank, and farther south it is continuous with the Navesink, owing to the disappearance of the Red Bank. It is conformably overlain by the Vincentown except where overlapped by Miocene formations. It is the Middle Marl of Cook, the Sewell marl of Clark, and is a part of the Rancocas group.

Vincentown sand.—The Vincentown sand presents two phases, a calcareous or limesand, semi-indurated, and largely a mass of broken bryozoan, echinoid, coral, and other calcareous remains, and a glauconitic quartz-sand phase. The two phases occur in alternating layers, although the former is more common in the basal portion, particularly to the south, while the quartz-sand phase predominates in Monmouth County. The fauna of the limesand phase contains large numbers of bryozoa, echinoids, and foraminifera, while in the

siliceous phase elements of the Hornerstown fauna occur in association with forms characteristic of the calcareous phase. Its thickness varies from 25 to 70 feet, but well-borings have shown that it thickens greatly down the dip. It rests conformably upon the Hornerstown marl and is overlain conformably by the Manasquan marl or overlapped by Miocene beds. It includes the "limesand" and "yellow sand" of Cook, the former of which was regarded by him as a part of the Middle Marl.

Manasquan marl.—The Manasquan marl in its lower portion (13–17 feet) is composed chiefly of glauconite, but the upper part (8–12 feet) is made up of very fine sand mixed with greenish-white clay, piles of which look like heaps of ashes—hence the name "ash marl." The fossils are not abundant and are poorly preserved, the commonest occurring also either in the Hornerstown or Vincentown. Its thickness is about 25 feet. It corresponds to the "green" and "ash" marls of Cook's Upper Marl bed and is the youngest of the Cretaceous formations exposed in New Jersey. It probably rests conformably upon the Vincentown and at most exposures is succeeded unconformably by Miocene or Pleistocene deposits, although locally it is overlain by a bluish marl of Eocene age without apparent unconformity.

Correlation of the Hornerstown, Vincentown, and Manasquan.—The faunas of these three formations are closely related, and form a larger fauna sharply separated from the Ripleyian fauna of the underlying Magothy and Tinton beds. This fauna has not been recognized south of Maryland. It shows certain affinities with the lower or Maestrichtian division of the Danian series of Western Europe (Weller).

EOCENE SYSTEM

Shark River marl.—Eocene deposits in New Jersey are limited in outcrop to small areas near Long Branch in Monmouth County where a mixture of greensand and light-colored earth 11 feet in thickness and carrying Eocene fossils rests without apparent unconformity upon the "ash" marl of the Manasquan. The conformity, however, is only apparent, well-borings indicating that the Shark River, as this formation has been called, probably overlaps the Cretaceous.

Clark[1] considers that it is not possible to correlate the Shark River marl with any other known Eocene deposits and regards them as probably older than the Eocene of Maryland. By some other authors, however, they have been placed above the Maryland Eocene.

MIOCENE SYSTEM

Beds of known Miocene age are widely distributed in the coastal-plain portion of New Jersey, where they overlap the Eocene and many of the Cretaceous formations. At the north they rest on beds ranging from the Eocene to the Hornerstown marl, while in the southern portion outliers are found upon the Mount Laurel sand.

Kirkwood formation.—Under the term Kirkwood have been included all beds of demonstrable Miocene age which outcrop in New Jersey. These beds vary lithologically in different regions, but they are predominantly fine micaceous quartz sands often delicately banded in shades of salmon-pink and yellow. Black, lignitic clays occur in many localities at or near the base. In the southern portion (Salem County) a thick (80–90 feet) bed of chocolate or drab-colored clay occurs, above which there are (or were formerly) exposures of a fine clayey sand containing great numbers of shells (the Shiloh marl of many reports), which, in the localities where it occurs, forms the upper bed of the Kirkwood. The thickness is about 100 feet or more along the outcrop. On the basis of the abundant fauna in the beds at Shiloh, the Kirkwood is believed to correspond in a general way with the Calvert formation of Maryland, the lowest division of the Chesapeake group.

Well-borings at Atlantic City, Wildwood, and other points along the coast have demonstrated the presence there of a great thickness of Miocene strata not apparently represented in outcrop. At Atlantic City clays, sands, and marls from 390 to 1,225 feet below tide carry Miocene fossils, and at Wildwood those from 300 feet to 1,090 feet and perhaps to 1,244 are Miocene. From the fossils it is evident that strata referable to the St. Marys, Choptank, and Calvert horizons of the Chesapeake group are present.

Cohansey sand.—Overlying the Kirkwood at its outcrop is a formation composed chiefly of quartz sand, locally with laminae and

[1] *Report of the State Geologist of New Jersey*, for 1893, p. 346.

lenses of light-colored clay and occasional lenses of gravel. This formation outcrops over a wider area of the coastal plain than any of those heretofore discussed. Obscure casts of molluscan shells have been found in it, but these are of no value in determining its age. Plant remains from near Bridgeton indicate a flora comparable with that of certain European upper Miocene localities. It dips southeastward 9 or 10 feet per mile, and overlies the Kirkwood with seeming unconformity.

Inasmuch as sands and clays similar to the Cohansey are revealed in borings along the coast and there overlie clays carrying Miocene fossils characteristic of the St. Marys, the highest division of the Chesapeake group, the Cohansey apparently belongs to a still later stage of the Miocene or perhaps even to the Pliocene. It is possible, however, that as now defined it may represent in part at least the shoreward phases of the fossiliferous Miocene clays found in the borings along the coast, and that it should be correlated with the Choptank and St. Marys of Maryland. In the light of all data at present available, however, the former view seems most probably the true one.

PLIOCENE SYSTEM

Beacon Hill formation.—Under the term Beacon Hill there were described certain beds of gravel and sand occurring as outliers on the higher hills of Monmouth County. Later the sand beds were correlated with the great body of sand now included in the Cohansey formation, leaving only the gravel in the Beacon Hill formation. It is chiefly quartz, but contains much chert and some hard sandstone and quartzite. The chert pebbles are uniformly much decayed and are frequently very soft. The quartz and quartzites are often more or less corroded. The formation occurs as isolated remnants on some of the highest hills of the coastal plain. It is perhaps to be correlated with the Lafayette formation farther south.

PLEISTOCENE SYSTEM

The Pleistocene formations of New Jersey are glacial and non-glacial, the former occurring in the northern counties, the latter chiefly on the coastal plain. The glacial or glacially derived deposits will first be considered.

GLACIAL DEPOSITS

Kansan or pre-Kansan drift.—Glacial drift, both stratified or unstratified, greatly antedating the moraines of the Wisconsin epoch, occurs more or less discontinuously south of the Wisconsin moraine, to a maximum distance of 23 or 24 miles. In the Highland belt it is thicker and more continuous in the wider valleys than on the ridges, while on the Triassic piedmont plain it caps isolated and more or less flat-topped hills in relations which indicate prolonged erosion, since its deposition. The great age of this drift is indicated by the fact that the main streams have sunk their channels 100 feet and have opened wide valleys on extremely gentle gradients since it was formed. Its complete oxidation and leaching and the disintegration in situ of even large bowlders of gneiss and granite deep within its mass are other evidences of its great age. It is believed to be at least as old as the Kansan drift and may be even older.

Wisconsin drift.—A great terminal moraine of the Wisconsin ice-sheet crosses the state from Perth Amboy to Belvidere. Narrow valley trains of glacial gravels characterize some of the southward drainage lines, notably Delaware Valley, and locally overwash plains are conspicuous topographic features. North of the moraine the rock surface is covered by the usual assemblage of drift deposits, stratified and unstratified. At least two definite halts in the ice retreat are marked by recessional moraines and valley trains which head in them. The warped shorelines of an extinct glacial lake in the upper Passaic Valley indicate a differential elevation of the northern part of the state of about 2 feet per mile, since the retreat of the Wisconsin ice-sheet.

NON-GLACIAL DEPOSITS

The non-glacial Pleistocene deposits consist of gravels, sands, and some clays, chiefly of fluviatile origin, but deposited partly at least in connection with estuarine conditions. Three formations have been differentiated, the Bridgeton, Pensauken, and Cape May, partly on lithologic and partly on topographic grounds. Each of these represents a period in which both erosion and deposition occurred in this region but in which deposition predominated. They were separated by intervals in which on the contrary erosion prevailed over deposition,

although the latter did not cease. Consequently there are, in addition to the deposits referred to these formations, others accumulated during intervals of erosion, whose lithologic, topographic, and age relations are not so clear. Changes of elevation are believed to have accompanied and to some extent to have caused the alternate periods of erosion and deposition, but it is not believed that subsidence was so great as to have depressed all the region in which these beds are now found below sea-level.

Bridgeton formation.—The Bridgeton formation is essentially gravel and sand, the material having been derived from the Beacon Hill, Cohansey, Miocene, Cretaceous, Triassic, Paleozoic, and crystalline formations. Material from the crystallines and Triassic is almost uniformly friable and crumbles readily. Some bowlders are so large and of such a character as to have hardly reached their present position without the aid of floating ice. It occurs as outliers capping high hills, and on divides, and is manifestly now only a remnant of an ancient deposit in large part fluviatile and referable in time of origin to a very early glacial epoch.

The Bridgeton is comparable in a general way to the Sunderland of Maryland, although their limits may not be the same and somewhat diverse views of origin are held by workers in the respective fields. After the deposition of the Bridgeton, there was a long period of erosion during which much of the Bridgeton was removed, particularly in Delaware Valley and along the broad belt of low land stretching across the state from Bordentown and Trenton to Raritan Bay.

Pensauken formation.—The Pensauken formation is chiefly gravel and sand, although locally it contains beds of clay. It frequently much resembles the Bridgeton and cannot always be distinguished from it on lithologic grounds. Where both are present, however, it uniformly occurs at lower levels and has suffered less erosion. It obliterated the smaller and partially filled the larger valleys eroded in post-Bridgeton time, forming broad flood-plain deposits along the drainage lines. The coastal portion of the state was more or less submerged during this period of deposition but the Pensauken formation is conceived to be one due primarily to fluviatile rather than marine or littoral conditions. Since glaciated material

occurs sparingly, it is correlated with a glacial epoch—one, however, which long antedated the Wisconsin drift sheet. In relation to other Pleistocene deposits, it corresponds roughly to the Wicomico of Maryland. Pensauken deposition was followed by a long period of uplift during which the formation was much eroded, nearly all of it being removed from areas favorably situated for erosion.

Cape May formation.—At a later time there was a slight submergence to the extent of 40 or 50 feet below the present stand of the land. During this period terraces were formed at many points along the coast and in valleys which were not submerged. The deposits of this stage constitute the Cape May formation and are believed to correspond in age with those of the last glacial epoch or possibly its later stages. The estuarine terraces along Delaware Bay are continuous with those along Delaware River above Trenton which head in the terminal moraine of the Wisconsin ice-sheet. While along the coast and lower Delaware River the terraces do not exceed 40 feet in height, and are lower than the Pensauken terraces in the same region, yet along the tributary streams they rise to much greater elevations, in some cases equaling that of the Pensauken or Bridgeton.

Since the deposition of the Cape May formation there has been an elevation of the land to something above its present level. Still more recently, subsidence has been in progress and is apparently now going on.

SECTION FOR NEW JERSEY

PLEISTOCENE

GLACIAL		NON-GLACIAL	
Wisconsin Drift	0–250+ feet	Cape May formation	0–20 feet
Unconformity		Unconformity	
Early Glacial Drift	0– 30+ feet	Pensauken formation	0–20+feet
		Unconformity	
		Bridgeton formation	0–30 feet
		Unconformity	

PLIOCENE ?

Beacon Hill gravel	Variable

MIOCENE ?

Cohansey formation	100–250 feet
(*Sand and clay lenses*)	
Unconformity	

MIOCENE	
Kirkwood formation	100 feet
(*Sand and clay*)	
Unconformity	
EOCENE	
Shark River marl	11 feet
CRETACEOUS	
Manasquan marl	25 feet
Vincentown sand	25–70 feet
Hornerstown marl	30 feet
Tinton bed	10–20 feet
Red Bank sand	0–100 feet
Navesink marl	25–40 feet
Mt. Laurel sand	5–60 feet
Wenonah sand	35–20 feet
Marshalltown clay-marl	30–35 feet
Englishtown sand	20–100 feet
Woodbury clay	50 feet
Merchantville clay	60 feet
Magothy formation	
(*Sand and lignitic clay*)	25–175 feet
Unconformity	
Raritan formation	150–250 feet
(*Sands and variegated clays*)	
Great unconformity	
TRIASSIC	
Brunswick shales	6,000–8,000 feet
Lockatong argillites	3,500 feet
Stockton arkose sandstones	2,300–3,100 feet
Three or more basalt flows and one or more intrusive diabase sills at various horizons. Total maximum thickness	3,000 feet
Great unconformity	

DEVONIAN

UPPER DELAWARE VALLEY		GREEN POND MT. REGION	
		Skunnemunk conglomerate	1,500± feet
		Bellvale sandstone	1,800 feet
Marcellus shale	Traces	Pequanac shale	1,000 feet
Onondaga limestone	Undet.	Kanouse sandstone	215 feet
Esopus grit	375 feet	Not recognized	
Oriskany formation	170 feet	" "	
(*Siliceous limestones and sandstones*)			

Kingston or Port Ewen shale	80 feet	"	"
Becraft limestone	20 feet	"	"
New Scotland beds (*Cherty limestone and calcareous shale*)	160 feet	"	"
Stormville sandstone	0–10± feet	"	"
Coeymans limestone	40 feet	"	"

SILURIAN

Manlius limestone	35 feet	Not recognized	
Rondout limestone	39 feet	"	"
Salina: Decker Ferry limestone	52 feet	Decker Ferry limestone	
Salina: Bossardville limestone	12–100 feet	Not recognized	
Salina: Poxino Island shale	Unknown	"	"
Salina: High Falls shale	2,300 feet	Longwood shale	200+ feet
Salina: Shawangunk conglomerate	1,500 feet	Green Pond conglomerate	1,200–1,500 feet

Unconformity

ORDOVICIAN

Martinsburg shale	3,000 feet
Jacksonburg limestone	125–300 feet

Unconformity

Kittatinny limestone	2,500–3,000 feet
CAMBRIAN	
Kittatinny limestone	
Hardyston quartzite	5–200 feet

Great unconformity

PRE-CAMBRIAN

Byram and Losee gneiss—rocks of various types, intrusive in older sedimentary rocks	Unknown thickness
Pochuck gneiss, in part intrusive, in part metamorphosed sediments	
Franklin limestone—white crystalline limestone penetrated and surrounded by younger intrusives	Unknown thickness

Reviews

Die Alpen im Eiszeitalter. Von Dr. Albrecht Penck, Professor an der Universität Berlin, und Dr. Eduard Brückner, Professor an der Universität Wien. Gekrönte Preisschrift. Leipzig: Chr. Herm. Tauchnitz, Verleger. In drei Bänden, S. xxxviii + 1200, mit 136 Abbildungen im text, 30 Tafeln, und 19 Karten. Vollständig in 11 Lieferungen à 5 Mark.

This voluminous work, by two of the leading glacialists of Europe, has been seven years in course of publication, the first Lieferung having appeared in December, 1901, and the eleventh or concluding Lieferung in December, 1908. It represents the vacation work of each of these authors for a period of about twenty-five years, and is largely a labor of love, the greater part of it having been carried on independent of official surveys and at private expense.

The plan of the work embraces three volumes, of which the first deals with the glaciations on the north of the eastern Alps, the second on the north of the western Alps, the third in the southern Alps and eastern end of the Alps. The paging, however, is continuous so that the entire work may be bound in a single volume and it has but a single index. The comprehensiveness of the treatment of results of the many studies carried on by various students is shown by the fact that there are 547 different authors either referred to or quoted.

In the first volume, which is entirely the work of Dr. Penck, after a brief setting forth of the problems involved and the methods of study pursued, and a brief outline of leading features in the northern portion of the eastern Alps, attention is first called to the gravel outwash aprons and lines of glacial drainage displayed in the Alpine foreland. The morainic belts are then discussed and then the feeding grounds of the glaciers. Overdeepening is discussed in considerable fulness in relation to the Inn valley system and the rules for overdeepening by glacial erosion are briefly considered.

It was in this field that Penck first worked out the intricacy of the glacial history, and it was done largely through a study of the out-wash phenomena or glacial drainage. It was found that there are four different old fluvioglacial gravel deposits, each of which is connected with a drift sheet. The

gravel deposits are known as the "Aeltere Deckenschotter, Jungere Deckenschotter, Hochterrassen, and Niederterrassen," while the corresponding drift sheets are named "Gunz, Mindel, Riss, and Würm," the names being taken from type localities in the Alpine foreland. The relative ages of the deposits of each glaciation are determined by a study of the relative amounts of geologic work accomplished by erosion, sedimentation, and weathering since their deposition. The first two glaciations are found to be much more remote than the last two, and form what are called the older group, while the Riss and Würm form the younger group, yet the alteration of the Riss is sufficient to indicate that it is more than twice as old as the Würm. The classification here made was found to hold good throughout the entire Alpine field, and as a result of the wider study the relative ages of the several glaciations, as summed up in the concluding Lieferung, place the Riss three times as far back as the Würm, and the Mindel at least twelve times as far back as the Würm, while the Gunz is considered about one and one-half times as old as the Mindel, the data for estimating its age being rather imperfect. In this first volume Penck brings out clearly the minor oscillations shown in the last or Würm glaciation. To each readvance made by the ice he applies the term stadium and recognizes three that lie between the maximum limits of the Würm glaciation and the limits of the present glaciation, namely the Bühlstadium, Gschnitzstadium, and Daunstadium. These stadia are found to be capable of differentiation in many other parts of the Alps. This first volume also discusses briefly the interglacial deposits and the difficulties of their interpretation. It is the custom of these authors to class deposits as interstadial rather than interglacial except in places where the evidence is very clear that they were laid down in a much warmer climate than would be consistent with a glacial stage. Where, for instance, warm-climate plants are found to be imbedded in the deposit, as in the Hötting breccia near Innsbruck, the deposits are referred confidently to an interglacial time.

While the first volume is entirely from the pen of Penck, it should be stated in justice to the work done by Brückner, that the results of his studies in the Salzach district, which appeared in 1886 in the form of a monograph are here abstracted by Penck.

In the second volume which deals with the glaciation north of the western Alps, Brückner discusses the glaciers of Switzerland, while Penck discusses the Rhein glacier and the portion of the Rhone glacier in France and the Isère glacier. Penck also discusses the Quaternary fauna and Paleolithic man in the Rhodanischen district and on the north side of the Alps. The four glacial stages brought out in the first volume are clearly

represented in the district covered by the second volume, but there is an interesting difference in the relative extent of the Riss and the Mindel glaciations in the two districts. In the eastern district the moraines of the Mindel glaciation generally extend beyond the limits of the Riss, but in the western district the Riss usually marked a greater extent of glaciation. Brückner has suggested elsewhere that a considerable part of the Quaternary uplift in the western Alps may have fallen in the Mindel-Riss interglacial time, and that this, rather than a greater depression of the snow line, accounts for the great extension of the Riss glaciation in that region. In the present discussion, however, the question is left open as to whether the Riss or the Mindel experienced the greatest depression of the snow line. Both glaciations were more extensive than the Würm and also than the Gunz. This western region is exceptionally favorable for studying the relations of the Quaternary fauna to glaciation, and also Paleolithic man in his geologic relations. The transformation of the fauna of the glacial period is found to correspond closely to the change from glacial to interglacial conditions. On the north side of the Alps there appears an Arcto-Alpine fauna characterized by the mammoth, wooly rhinoceros, and reindeer, and an interglacial fauna characterized by the ancient elephant, *Rhinoceros Mercki*, and the deer. In Switzerland there is a sharp line separating the two Arcto-Alpine faunas from an intermediate interglacial fauna, though there are occasional occurrences of a mixing of the two faunas, for example of the deer and the reindeer. The geographic extension of the localities in which each of the Arcto-Alpine faunas occurs furnishes a basis for correlating their occurrences with stages of the glacial period. The older fauna comes up about to the limits of the Riss glaciation, while the younger fauna extends to the limits of the Würm, in fact it extends about to the limits of the Bühlstadium, and thus shows its somewhat close correspondence with the Würm glaciation.

The stage of human culture apparently prevalent at the time of the Riss-Würm interglacial period is that designated the Moustérien. By the close of the Würm glaciation the culture had advanced through the Solutréen to the Magdalénien. What is regarded by Penck as the most impressive case of the occurrence of a Moustérien type of artifacts with an interglacial fauna came to notice subsequent to the publication of this volume, but is discussed by him in the eleventh or concluding Lieferung. It is known as the Wildkirchli locality and is found in the Ebenalp of the Santis, east of the upper Rhein and south of Wallen See. Explorations by Emil Bächler, of a cave which stood above the limits of glaciation in that region, at an altitude of about fifteen hundred meters, shows the presence of hundreds

of stone artifacts, of the Moustérien type, imbedded with an interglacial fauna represented by the cave bear, cave lion, *Cervus Elaphus*, etc., in about five meters of cave earth, which is covered by rubble to a depth of 0.8 meter.

Penck holds that the cave earth calls for a thick vegetation in the district above the cave, and that the presence of these animals also strongly suggests such vegetation. He concludes that when these bones and artifacts were imbedded this region was warmer than now, for the cave is near the present timber line. There is no evidence that the fauna, whose remains are here imbedded, has occupied the region since the last or Würm stage of glaciation. This fact, taken with the stage of culture shown in the artifacts, gives a strong presumption of, if it does not clearly prove, man's presence there prior to the Würm stage of glaciation. Other instances, which have been cited to indicate man's presence prior to the last glaciation, such as those in the French Jura at Conliége, and Hautecour, are in Penck's opinion less clearly interpreted than the Wildkirchli.

In the third volume the Durance and several small glaciers on the west side of the southern Alps, as well as the glaciers on the east side of these Alps, are treated by Penck. Those on the south side of the Alps in northern Italy, are discussed in part by Brückner. Of those in the eastern Alps the Save glacier is discussed by Brückner, while the Drau and those of the Mur district are discussed by Penck. The conclusion (Schluss) which contains a résumé of the physiographic and climatic conditions, and the chronology of the glacial period, is by Penck.

The moraines formed on the borders of the Po plain in northern Italy reach enormous proportions, one on the edge of the Dora Baltea glacier attaining a height of about 500 meters above the low plain which it incloses, while those on the borders of Lago di Garda reach a still greater height above the bed of the lake. It is shown by Penck that the great Dora Baltea moraine, as well as those of several other glaciers, were formed mainly prior to the last or Würm glaciation. This was also the case on the north side of the Alps, but it has not been so clearly worked out in that region, though the outwash in the earlier stages points to more vigorous glaciation than obtained at the Würm stage of glaciation.

In the conclusion, which covers 36 pages, several points are more clearly presented than in the somewhat diffuse detailed discussion. Among these are: (1) The snow line of the several glacial stages in comparison with that of today; (2) the causes for the depression of the snow line; (3) difference between snow line and timber line in the ice age; (4) position of the snow line on the glacier surface, and the conditions of the zone of waste and zone

of accumulation; (5) the rapidity of Alpine glacier movement in the ice age; (6) aspect of the different parts of the Alps in the ice age; (7) character of the fauna and flora on the north side of the Alps; (8) the loess; (9) the climate curve of the glacial period; (10) absolute length of postglacial time and of the entire glacial period.

We cannot enter into a review of each of these subjects but will speak only of the loess, and of the estimate of the absolute length of the glacial period. Typical fossiliferous loess is rather rare in the entire circumference of the Alps. Usually the deposit to which this term has been applied is a loam having some loess characteristics. This loam is best developed north of the Alps and is present on each of the older drift sheets, but not on the younger or Würm drift. Where there is an overlap of drift sheets it is found between them, in the position of an interglacial deposit. But while interglacial in position its fauna is not entirely of an interglacial type of warm climate animals. The mammalian remains in it are usually of the Arcto-Alpine type. Penck makes the suggestion that the loess was deposited in advance of a stage of glaciation in a sort of tundra condition with scanty vegetation. That the loess of the Riss-Würm interval closely preceded the Würm glaciation is indicated by the character of artifacts found at its base. They are closely allied to those which followed the Würm glaciation. The solution of the loess problem it is thought may be worked out more satisfactorily in the broad loess-covered areas of eastern Europe than in the rather limited area on the borders of the Alps.

As to the absolute duration of post-Würm time and of the entire glacial period, Penck attempts only to present data that will serve to indicate roughly its order of size. From Heim's estimate on the rate of growth of the Muota delta and similar estimates elsewhere in the Alps it appears that the Bühlstadium of the Würm stage of glaciation was reached between 16,000 and 24,000 years ago. It is safe to conclude, therefore, that the culmination of the Würm glaciation was somewhat more than 20,000 years ago. This estimate is borne out by a study of the Swiss lake dwellings in their geologic relations. They are more recent than the Daunstadium, and yet lie back at least 4,000 to 4,500 years. Inasmuch as the changes effected by geological agencies on the drift of the Riss glaciation are fully three times the amount effected in the drift of the Würm stage and the changes in the Mindel drift twelve times that in the Würm, the Riss glaciation would have culminated fully 60,000 and the Mindel 240,000 years ago.

The illustrations which accompany the work embrace many excellent photographs and several good maps as well as numerous diagrams. Among the maps that of the Etsch glacier and the moraine amphitheater of Lago

di Garda, and the map of the Drau glacier and its neighbors, are the most complete, since they indicate the upper limits of glaciation by means of isohypsal lines. The data for such maps involve a vast amount of work such as it was not possible to extend over the entire Alpine field. As a rule each determination of the upper limits of glaciation required an all-day climb. Penck once remarked, in the presence of the reviewer, that his ascents and descents of mountains in the Alps involve a distance sufficient to reach from the Alps to the South Pole, or from the Alps to the North Pole and back again. One who has not attempted Alpine work can scarcely appreciate the great labor involved in carrying out such a study as that accomplished by Penck and Brückner. The only serious defect noted in this publication is the absence of a general map of the entire Alpine region, though this is offset to some extent by the adoption of a uniform scale (1:700,000) for the several maps of the sections of the Alps. It is also to be borne in mind that even at the culmination of glaciation the Alpine region did not support a continental ice mass. The glaciers which became united on the Alpine foreland were of the Piedmont type, and many glaciers remained entirely independent throughout their course.

Die Alpen im Eiszeitalter, although an expensive publication, the cost of the eleven parts being 55 Marks, or about $13.00, cannot well be left out of the library of any active geologist, and should be included in every university library. By those who have not a command of the German language a large amount of information may be obtained from the excellent maps, views, and diagrams.

FRANK LEVERETT

The Life of a Fossil Hunter. By CHARLES H. STERNBERG. Introduction by HENRY FAIRFIELD OSBORN. New York: Henry Holt & Co.

The author of this interesting personal narrative is one of the oldest vertebrate fossil collectors in America. Mr. Sternberg made his first expedition in the Kansas chalk for Professor Cope during the summer of 1876. Specimens collected by him from many of the vertebrate-bearing horizons of the western United States are to be found in many of the museums of America and Europe. Beginning his work at a time when America had but three vertebrate paleontologists, Mr. Sternberg has seen the science advance until now there are over forty specialists engaged in it and to this advancement he has contributed not a little by his industry and skill as a collector. He has persevered in his chosen work in spite of hardships and financial difficulties. His wide acquaintance with paleon-

tologists throws side-lights on the personnel of the profession and especially interesting is his characterization of Cope with whom he was associated for years.

A few errors of a minor character which subtract little from the general readability of the book should be mentioned. Mr. Sternberg's first expedition to the Kansas chalk was in 1875, not in 1876. The restoration of Triceratops, opposite p. 270, is obsolete, as is that of Elasmosaurus, opposite p. 123, and they should not have been used. Lysorophus, mentioned on p. 258, as a lizard and a connecting link between amphibians and reptiles, has lately been shown by Professor Williston to be a Urodele and a much more highly specialized form. The author's zeal has sometimes led him into the mistake of unduly magnifying the importance of museums containing his own collections to the derogation of certain others, as for instance the statement on p. 112, accredited to Professor Osborn, that the Munich Museum contains the finest collection existing of specimens from the Kansas chalk, whereas as a matter of fact the collections from this horizon in the museums of Yale University and the University of Kansas far exceed in importance those of any other.

C. L. B.

Geological Survey of Ohio. By J. A. Bownocker, State Geologist, N. W. Lord, and E. E. Somermeier. Fourth Series. Bulletin No. 9. 1908. Coal. 342 pp., 7 pls., 2 maps. Columbus, 1908.

This report is the first under the supervision of the present state geologist. It deals entirely with the coals. Part I treats those of the Monongahela formation or the Upper Productive Measures, and Part II deals with the four seams of the Allegheny formation or the Lower Productive Measures. One hundred and fifty-one sections are given with descriptions, analyses, and calorific values. Chap. viii is an interpretation of the chemical and physical tests. Chap. ix is a description of the methods used in the analyses.

C. J. H.

32nd Annual Report of the Department of Geology and Natural Resources of Indiana. By W. S. Blatchley, State Geologist. 1158 pp., 79 pls., maps. Indianapolis, 1908.

The various reports of the soil survey are given in the first part of the work. The early report of Hopkins and Siebenthal on the Indiana Oölitic limestone is revised to keep pace with the growing industry which in 1907 amounted to three and one-half millions. The production of petroleum has declined, due to the migration of operators to other states. The report of

the inspector of mines is largely statistical. The supervisor of natural gas outlines improvements for the abuses now allowing unnecessary waste of a valuable resource. The major portion of the volume is upon the stratigraphy and paleontology of the Cincinnati series. The smaller alternation of shale with limestone in the Cincinnati beds is attributed to climatic conditions while the sudden change of fauna and type of sediment is attributed to epeirogenic causes. The Richmond of Indiana is considered the time equivalent of the Medina of New York. A complete résumé of the fossils described from the series is given. C. J. H.

Wisconsin Geological and Natural History Survey. E. A. BIRGE, Director, and L. S. SMITH. Bulletin No. XX. Economic Series, No. 13. Water Powers. 354 pp., 52 pls. Madison, 1908.

After a brief description of the physical geography of the state, the author divides the work into two parts: the first dealing specifically with the water-power resources of northern Wisconsin, and the second with those of southern Wisconsin. C. J. H.

Waste of Our Fuel Resources. Address of DR. I. C. WHITE, State Geologist of West Virginia, at the Conference on the Conservation of Natural Resources, held at the White House on the afternoon of May 13, 1908.

The extent of the large deposits of coal, petroleum, oil, and gas is briefly stated. The wanton waste of them is characterized in a forceful manner. Our industrial rivals—France, Germany, and Great Britain—have no supply of the purest of fuels, natural gas, of which there are wasted in the United States 1,000,000,000 cubic feet daily, the equivalent of 1,000,000 bushels of coal. For every barrel of oil taken from the earth ten times its amount has been lost one-half of which may be saved. From 40 per cent. to 70 per cent. of the coal is irretrievably lost in mining.

C. J. H.

Oklahoma Geological Survey. BY CHAS. N. GOULD, Director, L. L. HUTCHISON and GAYLORD NELSON. Preliminary Report on the Mineral Resources of Oklahoma. Bulletin No. 1, 1908. 88 pp., 11 figs. Norman, 1908.

This bulletin is the first report of the recently formed state geological survey. Its purpose is to direct attention to the vast resources, to foster

home industries, and to discourage useless prospecting. The enormous deposits of coal, gypsum, asphalt, salt, oil, gas, shale, limestone, and clay are described, and their approximate locations given. Lead, zinc, granite, gabbro, porphyry, marble, tripoli, novaculite, and volcanic ash are important deposits. Iron and copper are too widely disseminated in the rocks to be of value. Gold and silver are not likely to be found. The gypsum and asphalt deposits are among the largest in the United States. The granite and porphyry are of the finest quality. The introduction of better means of transportation will stimulate the mineral industry of Oklahoma.

C. J. H.

Some Problems of the Formation of Coal. By DAVID WHITE. Reprinted from *Economic Journal*, Vol. III, No. 4, 1908.

The author states that typical coal plants grew in greatest profusion under a humid and equable, though not necessarily tropical, climate. The size and state of preservation of delicate plants is affirmative evidence of accumulation in regions of growth. Transported plant remains are characterized by their macerated condition.

Anaerobic bacteria are primarily indispensable as an agency in the decomposition of organic matter, forming algal, fundamental matter, or sapropel. The process which is essentially bio-chemical probably leads no further than the formation of peats, humus, sapropelic deposits, etc. In the dynamo-chemical stage of coalification the anthracites, bituminous coals, and lignites are metamorphosed from peats, lignites, etc. Devolatilization, the writer believes, is caused not by folding or faulting, but by deep-seated horizontal thrust movements. Lithification and partial dehydration are attributed to loading pressure. De-oxygenation and de-hydrogenation which are essentially chemical results are due rather to bio-chemical changes than to dynamic stress.

In a future paper the writer hopes to show clearly that de-oxygenation is a true index of the progress made in the formation of coal and its efficiency as a fuel.

C. J. H.